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INTEGRATED

METHODS / TECHNIQUES / STRATEGIES

INFRASTRUCTURE

Transport and water infrastructure go far beyond engineering. When thoughtfully and cohesively planned and designed, infrastructure enriches society in an economic, social, ecological, and cultural way.

This design guide bridges disciplines – from transport planning and urban design to hydraulic engineering and landscape architecture, offering an integrated approach to shape roads, railways, bridges, flood defences, and mobility hubs which are well-embedded in our living environment.

PERSPECTIVES / FEATURED DESIGNS

DESIGN GUIDE

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INTEGRATED

METHODS / TECHNIQUES / STRATEGIES

INFRASTRUCTURE

PERSPECTIVES / FEATURED DESIGNS

DESIGN GUIDE

Satellite photo of the southwestern delta in the Netherlands. [PD NASA Earth Observatory, Joshua Stevens]
Previous pages: night works on the railway grounds of Nunspeet station, Gelderland, 2024. [© Hollandluchtfoto, Bram en Maarten van de Biezen]

FOREWORD

The Netherlands is a unique country, shaped by the interplay of human effort and nature. Without great visionaries and our daily efforts, it would not exist. This is not only the result of the skilled work of designers, engineers, and builders. I believe it is also a thing of great beauty. The Afsluitdijk, our historical polders, the Delta Works, but also the railway stations and sustainable mobility corridors: beautiful technical designs that blend organically with their surroundings. Circular, with nature-based solutions. This infrastructure of water works and transport networks and everything that goes with it is the foundation of our country, the basis for our flood protection and safety, a prerequisite for our prosperity, economy, and society. Now and in the future.

It is important to realise that technology is an integral part of the country we live in, and that technology springs from ingenuity and imagination. This overview brings together the knowledge, experience, and inspiration gained over the past decades in the design and realisation of major Dutch infrastructure projects. It offers an insight into the power of Integrated Infrastructure Design: an integrated approach that focuses on people, technology, the environment, and policy.

This approach is a logical consequence of the current developments, in which social challenges are becoming increasingly complex and interconnected: climate adaptation, energy transition, urbanisation, and biodiversity restoration. Every project brings together engineers, ecologists, urban planners, lawyers, financiers, and residents. Their collaboration is not only decisive for the technical success of a project, but also for the quality of our living environment and our well-being. Connecting these worlds requires craftsmanship, curiosity, and mutual understanding.

The projects highlighted in this book show how the Netherlands is a global leader in the integrated design of infrastructure and water management. Smart combinations of functions – such as water safety and nature development, mobility and urban densification, energy infrastructure and landscape quality – form a flywheel that enables innovative solutions. These projects demonstrate Integrated Infrastructure Design is not just a methodology, but a culture of collaboration and continuous dialogue.

The Netherlands faces major challenges in the coming decades. The layout of our country, our mobility and our water management approach will determine how future-proof our society is; how adaptive and resilient we are. Integrated Infrastructure Design offers a compass for making those choices jointly, in a well-founded manner and with an eye for coherence.

At the Ministry of Infrastructure and Water Management, we will continue to invest in knowledge sharing and innovation, precisely because tomorrow's challenges require a broad perspective and an open mind. This book invites us to do just that. It is a source of inspiration for everyone who works on our beautiful country, where ingenuity, imagination, and technology have become part of our nature.

We hope you will be inspired by the designs and case studies presented in this design guide.

Jan Hendrik Dronkers
Secretary-General of the Ministry of Infrastructure and Water Management

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INTRODUCTION

Societies in densely populated deltaic areas rely heavily on transport and water infrastructure of diverse types and scales, such as roads, bridges, railways, stations, waterways, dikes, navigation locks, (sea)ports, and airports. From the earliest stages, human activities have been enabled by infrastructure as foundation and precondition for prosperity and safety.

Yet, continuous expansion is neither feasible nor sustainable within planetary boundaries, considering the developments society is facing, like population growth, environmental pressure and liveability, loss of biodiversity, geopolitical developments, resource depletion, and climate change.

At the same time, a large part of the current infrastructure is at the end of its technical lifetime, since much was constructed after World War II. This situation raises critical questions about the current state and use of infrastructure as well as its future availability and suitability. The loss of critical infrastructure could disrupt human activities when accessibility of locations becomes problematic or that our preparation for the effects of climate change, like sea level rise, excessive rainfall, or freshwater scarcity, is inadequate. Moreover, it is unclear what the systemic relations are and to what extent existing systems can be adapted or that system change and transition are necessary, as is the case for energy and raw materials. There is great uncertainty about how developments will unfold and whether there are sufficient time and resources available to provide an appropriate human response. These conditions create a decision-making impasse.

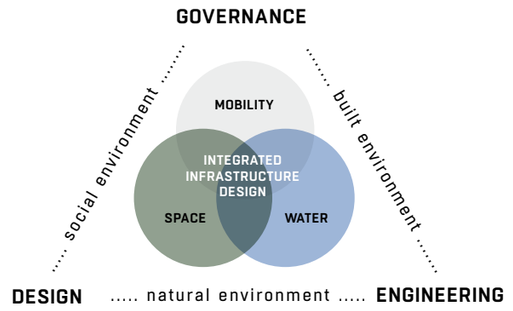
The key challenge is whether policy makers, designers, engineers, and constructors can jointly find solutions that reduce path dependency and avoid lock-ins for future responses under shifting conditions. Governmental infrastructure owners and its users, like business and residents, should not adopt a postponing or indifferent attitude, but act proactively, with a focus on value creation in a sustainable and balanced manner for people, planet, and profit. Mobilising creativity and innovation in practice and education is necessary to find answers. Integrated infrastructure design, the subject of this design guide, can contribute to this challenge.

WHY THIS DESIGN GUIDE? – The focus on integrated infrastructure design at TU Delft started in 2012, when a discussion took place among a small group of leading scientists from the architectural, urban, water and transport fields. The central question was why design, and engineering had drifted so far apart regarding knowledge development and educational practice, while at the same time socio-economic and infrastructure-related issues became more complex. Therefore, the need for collaboration was clear to all. The ongoing specialisation and fragmentation had to be mitigated somehow. To find an answer, an expert meeting was organised with practitioners from the design, engineering, and construction world. This resulted in a research and education agenda, which led to several interfaculty and interdisciplinary education programmes, studios, courses, concepts, and methods related to the vital systems for mobility, water and space and its integrated design (see figure).

Now, it is time to assemble the knowledge and experience of the involved scientists and experts from practice, based on more than ten years of interdisciplinary design education within a transdisciplinary context of social issues and infrastructure, and on an array of design studies for a future-proof built environment and its infrastructure, in close collaboration with practice. This design guide is a proposition to share insights with a broader academic and professional audience, and anyone who has interest in infrastructure and its meaning for people, planet, and profit.

This design guide shows inspirational and already realised designs and offers students and practitioners theoretical and practical insights from a vast array of firsthand approaches. A typical Dutch point of view on integrated infrastructure design is taken as starting point, with a focus on mobility, water, and space. As a low country in the delta of three rivers ending in the North Sea, the Netherlands face unique challenges that require specific solutions due to its geographical, cultural, and institutional contexts. However, content-wise, many of the discussed topics and methods, techniques, and strategies are also relevant for students and practitioners in other countries. The design guide

covers a range of disciplines and fields from policy, planning, design, engineering, economics, and social sciences. All these play a role in the development of integrated infrastructure as a common good, that have an undisputable impact on societies and their living environments.



Vital, interrelated systems for mobility, water, and space; the conceptual context for Integrated Infrastructure Design (IID).

HOW TO USE THIS DESIGN GUIDE? – The large variety of contributions in this design guide is structured by three main sections, matching the plan, analyse, and synthesise aspects of infrastructure design. Within each main section, further insight is offered by several thematic and case-based contributions, each of which ends with lessons that be deduced from these case studies. The related subsections on methods, techniques, and strategies offer a concise introduction of methodologies that may be of use to the reader. All main sections contain featured designs which are inspirational due to their integrative nature and the values they create. The closing section contains conclusions drawn in the making of this design guide. This section offers further outreach to practice, education, and research in order to disseminate the proposed paradigms for the practice of infrastructure development and management.

THE PLAN SECTION focuses on the 'front-end' of infrastructure development. This is a decisive phase for problem definition, the purpose and direction of further development, and the extent to which stakeholders' viewpoints, aspired values, and interests are considered. Thematic contributions cover the setting of political and governmental agendas, decision-making for a long-time span, the meaning of infrastructure for land value, urban and (inter)regional development, and stakeholder participation. The methods, techniques, and strategies discussed here are mostly supportive to planning, policy, and management processes.

THE ANALYSE SECTION provides insights and supports as to how to assess stakeholder expectations for an infrastructural intervention, as well as the boundary conditions and related risks. Apart from turning unknowns into knowns, the exploration of opportunities can reveal more value than initially aimed for. The thematic contributions discuss how spatial and engineering design can contribute to this. The methods, techniques, and strategies are mostly supportive to analysis and evaluation.

THE SYNTHESISE SECTION aligns stakeholders' expectations with reality. Will a realised design contribute in a sustainable and balanced manner to people, planet, and profit? The thematic contributions dive into various approaches and designs for flood protection and water management, ecological restoration, regional connectivity, local urban development, and public space. The methods, techniques, and strategies discussed here are supportive to design processes for diverse types of infrastructure and for design in itself.

WHAT IS NEXT? Looking at the whole picture, the cases and lessons from the thematic contributions and the featured designs indicate the contours and characteristics of an upcoming practice for infrastructure development and management, but this is not yet fully crystallised. This section offers and outlook on how to pin down, validate, disseminate, internalise, and institutionalise Integrated Infrastructure Design in practice, education, and research.



DISCUSS WITH STAKEHOLDERS
WHAT MATTERS AND WHY





De Groene Loper, Maastricht: newly built housing and recreational green cycling and pedestrian space designed by West 8, above the A2 tunnel. [© Jeroen Musch Photography] **/ Stadskwartier Noorderbos, Rotterdam: the rendering of metro station Meijersplein, as a part of the large housing development in the current airport location of Rotterdam-The Hague Airport, as envisioned in a study by Ziegler Branderhorst.** [© Ziegler Branderhorst]

SPACE AS COLLECTIVE GOOD

DESIGNING FOR THE LAND VALUE OF THE NEIGHBOURS

Transport infrastructure and its investments are generally regarded in relation to economic development. Accessibility and travel time for living and working are economic factors and the same applies to considerations for choices about location and transport. But how is infrastructure affecting land use? What value does it add and to what extent does it harm the living environment, nature, water, and air quality? What is the meaning of land use and land value? Can we calculate all financial, positive, and negative effects, thus arriving at the net sum of the accumulation of value?

The value of our physical environment is partly shaped by spatial designers and planners. However, infrastructure projects involve many stakeholders, from municipal councils to landowners and managers of infrastructure projects. Given the resources, the balance between financial calculation of the costs of construction on the one hand and value creation on the other hand is decisive, for e.g. the decisions on the location, capacity and route of a metro line, a crucial road connection, the renovation of a station, or the construction of a more robust river dike, new nature, etc. Effective and efficient use of land potentially provides society with net worth and money.

However, spatial designers or planners are not the only parties that determine the final form, location, and capacity in the case of spatial infrastructure projects. They act in a context in which many parties have a say, in which politics or a private party may determine a future reality. Spatial designers, together with professionals with other specialisations, give direction to various alternatives to an infrastructure project. In social cost-benefit analyses (SCBA) – the field of work of economists – such alternatives are calculated in relation to the 'null alternative', the development without a new project (Romijn & Zondag, 2012). This contribution does not deal in detail with the determination of land value or the SCBA of spatial plans. There is plenty of literature about this, both on the estimate of the costs of land acquisition, construction preparations, construction of an infrastructure project, and on the SCBA methodology. The latter is derived from the economic welfare analysis where the general question is whether the sum of prosperity and well-being will improve because of the realization of an investment project. Central to this is the valuation of goods and services that do not have market prices, but do have value, and how that value is approximated in euros. Such an approximation is called a shadow price, for example the price of pollution. [Social Cost-Benefit Analysis, page 200]

This contribution explains various relevant concepts from economics, which are relevant for the spatial designer – without any background in economics – in the design process. By using these concepts, spatial planners can create social value that counts as an extra benefit for society as a whole by means of spatial design. The aim is to design in such a way that not only the value of the object to be built or constructed is high, but also the value of adjacent objects, sites, and functions. Specifically: designing a building in such a way that the neighbour's building also increases in value. Such positive synergy is always mutual.

The value of space in relation to infrastructure interventions — This contribution discusses the concept of value in the spatial context of infrastructure projects. It goes beyond the financial price (costs) of the location that is being built on, but investigates what value means in the practice of designers. This will be done in two steps: firstly, to explain as concisely and clearly as possible what the relevant economic concepts are for integral designers of social and infrastructure projects and secondly what land value is in urban areas according to economic science. This will then be illustrated with

some practical examples, ranging from projects for which the design options by spatial designers have been calculated by economists, but have not (yet) been considered politically, to projects that have been realized and of which the actual social value has been determined before and after realisation of a project. Examples have been chosen from distinct phases, to show the various positions in relation to the political choices and to provide insight into the difference between the valuation before and after building the new building or infrastructure. Testing a previously made calculation to make the spatial designer aware that calculations before and after realisation might give different results. The construction costs themselves are usually disappointing (usual the budget overruns), but financial benefits and social value can be very low. Incorrectly estimating or missing a value in advance can bring decision-making to a standstill, while there are still potential valuable benefits that are not observed or considered.

The most important pair of concepts in economics for this topic are *price* on the one hand and *value* on the other. Value is a broader concept than price. Price, the money that is paid on the market to buy something, is an imperfect approximation of value. In the case of housing construction and real estate transactions, the land price is usually determined based on the residual land value method. When using the residual method, the land price (which the municipality then charges the developer) is equal to the expected market value of the real estate minus the expected foundation costs (construction costs, additional costs, general costs, profit margin for the developer), i.e. equal to the residual value of ready-to-build land. By reducing the development costs (demolition, preparation for construction and housing, planning costs, unforeseen costs, and contribution to the suburban facilities), we arrive at the residual value of the 'raw' land. Such a practical provision is important for the sale of land from municipalities to project developers. If infrastructure (such as a bridge) is needed, this will also be reflected in whole or in part in the budget by a municipal or higher-level government in the form of planned collective expenditure. This raises the question of the extent to which private parties can or should contribute to public goods (e.g. toll roads), knowing that this partly determines the value of land and ultimately the real estate. The extent to which such added value is allocated to private parties is a subject of ongoing discussion between the government and private parties.

Market analysis, externalities, and market forces

In addition to price and value, various economic concepts are indispensable for the analysis of value creation by designers and spatial planners.

Market analysis: Determining a shortage, equilibrium, or excess supply in a market — The first concept is *market analysis*. Each project (infrastructural, environment, urban real estate) will affect markets, such as demand for recreation, a rail connection, office space, or housing. This is the first step in the analysis that economists conduct for a future project that may offer a solution to a social issue. The question is whether there is structural scarcity (shortages) in a certain type of market. Nowadays, the housing market is extremely tight, which suggests that building more homes could be a useful project. Market analysis is about what effect additional construction has on the value and quantity demanded in such markets, and how the intended project affects the existing market. For example, there is no structural scarcity in the current market for offices and shops. Additional construction comes at the expense of the value of existing real estate, so that no additional value is generated in the entire market. The need for office floor space or retail space can be fully met with the existing supply. There are also other effects related to infrastructure, which could cancel each other out. For example, an above-ground metro line increases accessibility in an urban area but causes noise pollution. Better accessibility saves travel time for residents and office users, so that the attractiveness of those homes and offices increases; as a result, the value of homes and other real estate will rise. This will be reflected in a higher land value for the land on which those homes and offices are located. However, that also depends on additional noise pollution for homes along the metro line which will have a lower land value.

In addition to the influence of a project on travel time, house, and real estate value, it is also important in the market analysis to determine how the benefit (the usefulness, the benefit of a project after completion) 'lands' in society. That is the *distribution issue*. Who are the beneficiaries, and can they be taxed? Note that there are also negative benefits, and those who experience this may be eligible to receive compensation. This focuses on questions such as: does the benefit accrue to a specific group of individuals (e.g. the benefit of marinas for boat owners)? Can the benefit be allocated individually (e.g. airports, a lock or dike) or can individuals be excluded from the consumption of the benefits (e.g. a pop festival)? Can individuals or private parties realize the investment just as well or even better than the government (e.g. the operation of oil wells), or can only the government do that (e.g. the construction of tunnels)? Will use by one group come at the expense of the possibility of use by someone else (e.g. restriction of nature)? Does a good or service become more valuable if it is shared, such as knowledge, standardization or apps on smart phones? Is it at the expense of natural resources (e.g. a river as a natural source of drinking water)? The aim of these questions is to understand who benefits or suffers from a spatial intervention. Furthermore, it must be clear what kind of goods and services are involved. Economists regularly do this tacitly, but for professionals outside this profession it can be confusing. Therefore, we need to understand elementary concepts in economics such as private goods, collective (public) goods, club goods, or natural resources.

Such economic concepts provide insight into the type of effect that infrastructure aims to have as spatial design and how financial costs and social benefits (positive and negative) are attributable.

External effects: Who benefits or is disadvantaged by the actions of others? — Another related economic concept concerns the *positive and negative external effect* of an infrastructural intervention. These are the (un)intended effects, beyond the direct positive or negative benefits, which are related to the objectives of a project. A new road connection that improves the accessibility of a neighbourhood or region is intended to have a direct positive effect but causes more air pollution and noise pollution for others. In this example, these are negative externalities. External effects are positive or negative effects of a transaction between two parties for others, which are not included in the price. By including this in the price, one achieves *true pricing*. This may include air pollution, odour nuisance, or environmental pollution released during the production of goods (such as in manufacturing industries, nitrogen surplus from livestock farming, emissions of toxic substances, etc.) or consumption (pop festival, café space, night flights from an airport, etc.), without those who experience the nuisance being able to influence the decision. These benefits for some come at the expense of health, sleep, enjoyment of living, quality of water, nature and so on. They have a downward impact on the value of homes in locations where such effects occur. Drinking water producers must pay higher costs for purification due to contaminants in the source.
Positive external effects are also possible, such as the appearance of a park, arboretum, or concert hall, or the mutually constructive interaction among firms at a business park (e.g. Dutch Mediapark in Hilversum) or *spillover* in research & development of company laboratories in, for example, the Eindhoven region or around the TU Campus in Delft. Researchers meet each other and both companies and individual employees make use of the common labour market and university. Thus, a shared facility is created. Other examples are more clean water and biodiversity due to marsh construction (e.g. the Markermeer dike Enkhuizen-Lelystad created the nature reserve Markerwadden, with a widened dike body in the nature project that offers space for extra road lanes) or a better connection between two large cities and intermediate residential areas (the light-rail connection RandstadRail Rotterdam-The Hague). In the end, cities exist where prosperity is generated, both in

the form of gross domestic product (GDP) and a pleasant living environment, thanks to proximity which leads to low transport and transaction costs and a positive balance of externalities. Calculating the value of any project requires understanding of price and quantity, characterizing the types of goods and services for rivalry and excludability, and the existence of negative and positive externalities. [Benefit-Oriented Design, page 276]

Price and quantity in a market: An ideal distribution mechanism — The standard analysis of the market is where producers (suppliers, supply) and consumers (demanders, demand) meet and exchange a *quantity* (Q) of goods at a *price* (P). This is visible in the P/Q diagram in which the interaction between consumer demand and supply from producers is symbolized (Figure 1). The demand curve reflects all the points at which consumers are willing to pay price P for quantity Q of goods: the more expensive, the smaller the number of people who are willing to pay, and vice versa. The demand curve is therefore negative (if P rises, Q falls or if P lowers, Q rises). The supply curve represents the points at which producers want to offer a quantity of Q to consumers for price P. When the price is low, producers are willing to offer little, but when the price is high, they want to offer more. So, the supply curve is positive (if P rises, Q also rises).

At a high price, producers want to offer a large quantity, but consumers want to buy little. Supply and demand in this case are very different. Only a small proportion of consumers are willing buy something, the producers are left with stocks, and many consumers are left with unmet needs. The equilibrium price is the point at which the supply and demand line intersect. It is the only point in Figure 1 that exists in an undisturbed fully competitive market. After all, at this point, producers want to offer quantity Q for price P, and they know that they will not end up with structural surpluses; consumers want to pay the same price P for the same amount of goods Q, so that they do not end up with shortages. The opportunities of this simple graph to analyse markets are extensive. It can be used to analyse the effect of, for example, taxes, subsidies, excise duties, price floors or limits, quota (a production limit) and import duties.

This simple basic model provides numerous possibilities for further understanding all kinds of interventions, influence, or policy measures in a market. In the case of transport, it can be used to calculate travel time benefits for users of the future infrastructure that a project envisages. It can also be used to analyse the land market, relevant to spatial designers. The special thing about the land market is that the supply is fixed (Figure 2). The amount of land (space) is fixed though (the amount of building land is not), regardless of the price for the parties who want land and whether or not the construction of infrastructure comes at the expense of other uses (opportunity cost). Note that there is a difference between the surface area of the land and the surface area of the real estate that has been or will be built on that land. If more is built, the land will become more expensive.

The standard market analysis is based on assumptions: a homogeneous good, service, or property (houses of the same type are built on the same street); degree of transparency and information (is everything known about the subsurface?); availability of liquidity; sufficient participants on both sides (consumers and producers); degree of cooperation (consumer association, governments such as the Association of Netherlands Municipalities – VNG) or coordination (between builders, who may make tacit agreements among themselves or discuss with Rijkswaterstaat, as owner of national infrastructure, the use of expensive machines or unknown risks, e.g. the renovation of the Afsluitdijk or Van Brienenoord Bridge); and free entry (German construction companies bidding for Dutch infrastructure projects). Optimal market forces, in which prices and quantities can move freely according to market forces, almost never occur.

Numerous factors influence the final price and quantity supplied. For example, not every street is in the same city with the same conditions, nor are living environments and wishes never quite the same. The actual price (and quantity supplied) does not have to be correct, in the sense that all

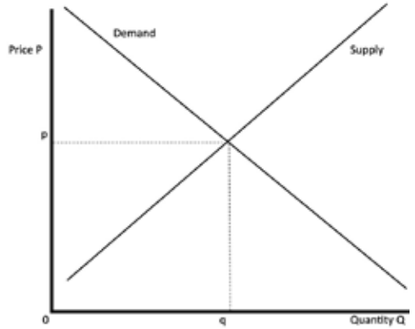


Figure 1 (left): Relationship between price and quantity in a supply-demand diagram.

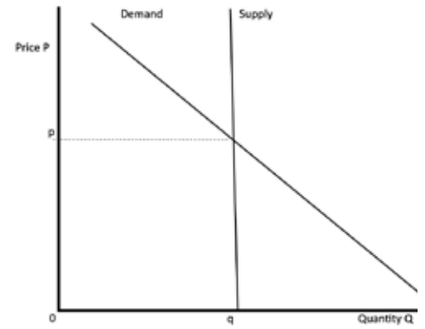


Figure 2 (right): Relationship between price and quantity in a supply-demand diagram of the land market.

Figure 3. Characterization of goods or services in relation to excludability and rivalry.
[Walter Manshanden]

	Excludable	**Non-excludable**
Rival	private	natural resources
Non-rival	club	collective

production costs and externalities have been included, that everyone's needs have been met and that there has not been too little or too much production. This is called *market failure*. We can say that virtually every market fails to some extent. Sometimes sellers of second-hand cars know more than the consumer (asymmetric information), there is only one supplier (monopoly) that charges too much, or one customer (monopsony) such as Rijkswaterstaat for the maintenance of motorways, the market is only accessible at high capital costs (in the case of construction of railway connections or complex construction projects), or there is collusion or even cartel formation between suppliers to raise and fix prices. It is up to the government to prevent such market failures. The idea that the government can fail must be also considered.

Public goods and (broad) prosperity

It is important in order to determine social value to assess what *characteristics* an investment good (for example infrastructure) or service has: is it a public or private good, a 'club good' or a natural resource (Figure 3)? This question is related to property rights, the extent to which money can be charged by the owner for the use of a good or service (excludability), and the extent to which the use of a good excludes that someone else from consuming (rivalry). For example, safety created by a dike is not excludable and non-rival. Everyone who lives in the area in question has the same degree of flood protection. The fact that one person experiences the benefit does not affect the extent to which another person experiences the same benefit. Parking garages are private goods: they are excludable and rival. An airport (as infrastructure) and aviation are seen as a public good by the central government but are not: every part of aviation (production of aircraft, use of aircraft and airports) has the characteristics of a private service. The traveller buys a ticket; the airline sells it to them in an efficient market, and the manager of Schiphol Airport (Schiphol Group NV) charges cost-covering landing fees to airlines and thus maintains the airport. The government imposes rules on this private activity in order to limit the negative externalities[1].
An example of a club good are toll tunnels, public transport or watching a film via the home cinema: it is excludable but not rival. Wood from natural forests, drinking water from a well, wild fish and natural gas are natural resources. They are produced by nature 'for free'. From a spatial-economic perspective, roads, squares, streets, public parks, nature reserves, the beach, and the sea are public goods: they are non-rival and non-excludable. What matters in spatial design is what kind of goods and services are intended by the proposed project and to what extent these are private property, club property, natural resources, or public goods.

The common good, commons and interest groups — A main topic for economists is *prosperity*, or *wealth.* Spatial designers give shape to physical reality, which means conditioning for that prosperity. The degree of extra prosperity created through the realisation of an infrastructure project, in urban areas and beyond, is then a crucial issue. In the background, however, economists are asking another question, namely who benefits. Spatial designers preferably take all *stakeholders* (not 'shareholders') into account in the spatial design process. Economists are taking an extra step here. When it comes to the distribution issue, they always think about the role of the government in relation to private parties regarding investments in infrastructure, because an infrastructure project is usually financed from tax revenues. The usefulness of the extra infrastructure is intended primarily for society, but it can be even broader, for example nature, the environment, and natural resources. If not, is it about public goods (services), club goods, or private goods and services? However, the concept of prosperity can be broken down into different layers. Concepts such as the *common good*, the *common*, and *lobbies* are related to this. [Stakeholder Analysis, page 112]

Prosperity, in the narrow sense, only refers to the gross domestic product (GDP): the sum of production of all goods and services minus the costs of all companies and institutions in a country. Its development is called *economic growth* (sometimes *contraction* during recessions). 'Broad' prosperity is about more: about everything that people value, including health, clean air and water, art, nature, climate stability, good relationships, family and friends, beautiful holidays, spiritual development, etc. Broad prosperity is about all aspects that concern prosperity and well-being. The concept of the common good is related to it. Its importance is regularly emphasized in literature (Reich, 2019; Daly & Cobb, 1990). For example, volunteering is 'for the common good'. This concept touches on *merit goods*. These are goods and services that should be available to everyone, regardless of income, such as education, health care, and public transport. The free market produces too little of these, so that the government must get involved. Other public benefits are peace, justice, and security. A 'common' is another concept, more a literal club or cooperative. This means the cooperative as an organization, like the first insurance companies, who produce a good or service jointly for the members of the club. A characteristic of such organizations is that they make a positive contribution without social costs.

This is different for an interest group or lobby. Interest groups deserve extra attention in the design process regarding broad prosperity. The public action theory (Mancur Olson, 1967) explains why small, specific sectoral lobbies can have a large socio-political effect for their own benefit, but at the expense of broad prosperity. In the Netherlands, there are examples of this: livestock farming (nitrogen), tobacco industry (health), and aviation (noise pollution and CO_2 emission) are subject to restrictive regulations by the government (e.g. by setting norms, extra pricing, etc.) and/or are major risks in the free market, so that they influence politics for regulation to their own advantage. The essence is that the private benefits for these interest groups always comes at the expense of social welfare: lobbies are 'enemies' of social welfare; they lower prosperity (GDP) and well-being (clean air, silence, clean water, stable climate). This can go a long way: the growth of the economy can stagnate when lobbies of languishing industries hold on to ageing and social unprofitable activities.

Market failure and regulation — Market failures occur in the production and consumption of natural resources and public goods. Natural resources are provided free of charge by the earth and nature. It is the basis of the 'tragedy of the commons': depletion of communal public pastures and natural resources; pollution of clean air and water; crowded cities due to free or cheap parking; and traffic jams due to free access to motorways. These goods are used by all to the detriment of social welfare. A price cannot be set on clean air and spring water, but it has a very high value. In any case, any price set on these goods does not reflect information properly about their scarcity. Parking in cities takes up scarce space. Driving during rush hour requires extra lanes, which are not necessary outside rush hour which is 20 hours a day. For parking, the government opts for parking fees, so that

the scarce space is redistributed and parking garages can charge money. In the case of traffic jams, the government chooses to increase the number of motorways and extra lanes for electoral reasons but does not introduce a price that reflects scarcity i.e., road pricing, where the price varies with the traffic jams during rush hour. Railway operators regulate the demand for train seats during rush hour by charging more money. If scarce public goods and natural resources are not given the right price according to their consumption, they will become depleted and exhausted.

It is reasonable to make agreements about consumption and production. Regulation by governments, such as catch quotas for fish and emission standards (CFCs, particulate matter, CO_2), environmental zoning, parking fees, road pricing, etc., is therefore desirable, but is not politically self-evident. Regulation is partly dependent on political preferences, lobbies, and the strength of the government. The role of the government is naturally aimed at counteracting market failures in the production such as natural regeneration of nature or fish stocks, consumption of public goods and natural resources from which people derive great benefit. Taxation, subsidies, target funding, legislation, regulation, and investments in infrastructure are the most important instruments. In urban areas, where there is great pressure on the natural environment, living environment and social safety, public goods and services are a structural part of well-being. It is precisely in large cities where utility – which can be equated to broad prosperity – is reflected in the land value. Government in large cities has a key role in organizing such collective facilities. *Land value* is central to this, and therefore a central concept in spatial planning and design.

The value of the neighbour's property

The previously introduced concept of external effect – in a positive or negative sense – is key for spatial designers. Infrastructure investments in large cities affect the value of locations (land) through positive external effects. Negative externalities are the opposite: other people experience the disadvantages of production and consumption of goods and services.

Externalities and impact on value — The influence of project effects (such as wind turbines on land) with a spatial external character on value is that the influence on house prices can usually be measured based on house values if there are enough homes. The effect of a wind turbine on house value can be determined by means of a *hedonistic price analysis*, in which the house value is explained by many factors and in which the variable 'distance to the wind turbine' is also included. Then it is possible to obtain an approximation of the influence of the height and distance of the wind turbine on the house value of nearby homes. In the case of noise nuisance from airport air traffic, this can be done per decibel based on house values within noise contours. Similar techniques are used to determine the positive effect of greenery or parks on the value of real estate, etc.

In regional economics, for example, the following effects are known: (a) the negative value of wind turbines and solar meadows on house value (Dröes & Koster, 2021), (b) noise nuisance from aircraft at airports (e.g. Leijsen et al., 2006), (c) a positive value of proximity to greenery, forest, water and parks (Luttik, 2000; Rouwendal & Van der Straaten, 2008), (d) historicizing building (Buitelaar et al., 2014), (e) travel time (Knoope, 2023) and (f) CO_2 emissions (Aalbers et al., 2016). Spatial spillover in knowledge clusters through proximity is a crucial spatial condition in innovation policy (e.g. the Holst Centre in Eindhoven, Yes! Delft at TU Delft). In addition, there is a range of external effects of which a positive influence on the value of nearby real estate can be suspected or is even very plausible but has not (yet) been quantitatively determined. These are the quality of the design of public space, such as the type of paving stone, use of colour in window frames, detailing and harmony of the façade and the plinth, car-free streets, and many other factors that influence the value of the project to be built itself, but also (and especially) nearby objects. The essence is that a good design contributes to the value of 'the neighbour's property', i.e. it is an addition that others also benefit from without paying for it.

In theory, land value reflects the balance of such positive and negative externalities. This can be formulated more generally: the mutual proximity of all kinds of urban functions, households and businesses that provide all kinds of services and products to each other contributes to broad prosperity. This is the central building block of 'new economic geography', which considers the scale, concentration of knowledge, proximity, product variety, and monopolistic competition (many providers with unique products) in large cities (or networks of cities) as a prerequisite for broad prosperity. It consists of mechanisms that urban economists recognize in the economic development of a city in terms of the structure of the type of activity, its dynamics, and the average income. *Proximity*, *density*, *mix of functions*, *positive spatial externalities* and the *avoidance of negative externalities* are key to well-being in large cities. [Plan Review, page 100]

Land: Source of value creation — In large cities, transportation costs are inversely proportional to the value of the location in the city. Assuming a monocentric city model, the price of land far outside the city is 'zero', but the transport costs are high in terms of money and time. From the city centre to the outer edges, land prices fall, and transport costs increase according to Alonso's urban land-value model (1960, 1964, 1971). The land market is a very special market compared to 'normal' markets (Buitelaar, 2021; De Groot et al., 2010; Van Gent et al., 2021; Lubbe et al., 2011). The characteristic of the land market in a large city is that the supply of land is fixed. No more of it can be produced if the demand increases and land is not mobile as a production factor. It cannot be moved if prices are better elsewhere, such as capital or labour. The amount of land is fixed and only the price can move, and with it the number of floors that must be built on it to meet the extra demand. This requires specific trade-offs between costs and benefits (Teulings & De Groot, 2020). Unlike the users of his land, a landowner is not mobile, but the more popular the location is among users, the higher the value. An increase in the need for land is fully reflected in an increase in value. This makes the land market a very special market, which differs from more common goods and services. The land market in a city develops through all kinds of spatial interventions, including the construction of infrastructure. The *Henry George theorem* states, in simple terms, that spending (investments) in collective (public) facilities in cities – such as a metro line – increases the total land revenues based on land value by more than that amount.

The Henry George theorem: The single tax on land value — In 1879, Henry George published an influential book on social welfare, in which land value in the city is explained. George's observation was that, despite technological progress, urban poverty persisted: not everyone shared in social progress and growing prosperity. George argued that rising prosperity in cities led to higher land prices, but that landowners could attract a significant portion of that extra wealth. In a private land market, this additional prosperity will be in the hands of landowners. They skim off the rental income of real estate owners. These, in turn, demand high rents from tenants. Those who live or work in the buildings (retail, catering, businesses) pay relatively high rent. Thus, the workers in the cities remained poor; their wages went to the slumlords and pawnbrokers, who in turn paid to the landowners. This mechanism created an urban proletariat at the time.

A skewed income distribution leads to three problems. First, an urban lower class emerges that does not share in the additional prosperity that a city produces as a cohesive economic system. Secondly, there is a municipal financing problem. Thirdly, for a municipality to act as a guardian of the city as a 'common good', there is an investment issue. Investments in better public services lead to an increase in land value, which benefits all kinds of private parties. The solution that George advocated was a 'single tax on land value' – a tax on land value replaces tax on income. Such a tax is both fair and efficient. Those who benefit from the value they assign to living and working in an expensive location pay tax in proportion to the value they assign to it, based on a choice of location

that reflects their preference and their relocation mobility. Thus, what matters is the exchange between the costs of living/working at a location and transport costs. Land value incorporates all negative and positive externalities – a brilliant insight into urban life in 1879.

Investing in urban infrastructure pays off — A tax on land value is therefore the perfect tax because land is not mobile (labour and capital are). It was Nobel Prize winner Joseph Stiglitz who coined the term 'Henry George theorem' for this. The income that the city council receives from the tax serves to compensate the urban lower class to make use of all types of services and land-related subsidies on their housing and transport costs (charging a unit price regardless of distance), so that they can also share in all kinds of urban facilities such as healthcare, education, and museums. The city council also finances collective facilities such as clean public space, greenery, water, and sewers, and, last but not least, high-quality public transport, through a tax on land value. The social benefits of urban metro systems should not be underestimated. This means that investments in large cities are usually socially net profitable, which means that the SCBA prior to an urban investment project is always positive[2]. However, in most cases social and political realities and dilemmas come to the table, in which the landowners are in principle aiming for private profit, while the municipality, as guardian of the common good, is responsible for the social (broad) prosperity of the urban community. Both interests ultimately converge because of the intertwined spatial, positive external effects, but land and real estate owners can influence politics as an interest group. After all, private parties and the city council have the same interest in the high quality of the immediate environment and good accessibility of a location from the point of view of the urban system. In a dysfunctional political system, that common point is not reached.

The Henry George theorem fundamentally shows that land value is an important management tool for urban planners and designers because it provides information about locations. Project development therefore is not just about the increase in the value of a plot itself, but about the additional increase in value of the land in the vicinity of an investment project on a plot. It is about generating positive external effects on the environment that, from a social perspective, express the social profitability in a non-monetary sense. These positive externalities are reflected in a rising land value. A tax on land value also has the advantage that it encourages landowners to use the land; leaving it fallow or obsolete comes at a price. For a city council that assesses an urban investment project, it must take into account the additional benefits for the environment – apart from the purely financial costs and benefits – in whatever form (e.g. clean air and road safety, more charging stations, a maximum speed of 30 km/h). That is the aim of a programme of requirements – which, from the perspective of the urban economy, generates and redistributes additional wealth in the realisation of an urban investment project. It is also up to politicians to make social choices about the value of collective facilities.

Examples of social value creation

There are many examples of urban redevelopment projects in which the completion of an urban task is combined with greater quality of life, and even examples with an emphasis on the latter. A recent example of this is the opening of once filled-in waterways in the city centre of Utrecht. Older examples are the infrastructure projects from the VINEX locations (new urban extensions realised in the Netherlands in the 1990s and 2000s), and the renovation of existing stations and surroundings in Amsterdam, Den Haag, Rotterdam, Utrecht, Breda, and Arnhem (Nationale Sleutelprojecten – NSP).

This section gives three examples of urban (re)development projects or plans that focus on urban welfare and positive social effects in the project itself, as well as the environment and more broadly. The examples vary in degree of realisation: two projects that are fully completed and have also been studied afterwards, and a project that did not make it past the exploratory phase.

Tunnelling A2 Maastricht: High liveability benefits and increase in the value of real estate — The first is the tunnelling and public space project of the A2 motorway near Maastricht, called De Groene Loper ('green ribbon') (Figure 4). The problem was that the original A2 motorway at ground level was interrupted by junctions with traffic lights in the east of Maastricht. This caused loss of time for through traffic, air pollution, and noise pollution for local residents. The proposal was to solve this by tunnelling, with exits for local traffic. Above ground, space would be created for a park, homes, and other real estate. This would benefit traffic and the quality of life. The barrier that the motorway created between the city districts on both sides would also be removed. In the previous (ex-ante) study (Ecorys, 2006) into the effects, the costs were estimated at 725 million euros and the benefits at 774 million euros. The benefits consisted for the most part of travel time benefits for through traffic on the A2. For urban liveability and the barrier effect, a benefit of only 12 million euros was estimated. In 2016, during an interim evaluation after completion of the first phase, the costs were now 890 million euros (including fittings for the tunnel such as conversion of the A2 and connections, and construction of Parklaan, etc.).

After realization, the Netherlands Bureau for Economic Policy Analysis (CPB) estimated the liveability benefits of the tunnelling at 220 million euros in an ex-post study, considerably higher than the previously estimated 12 million euros (Tijm et al., 2018). This high amount was derived from the observed additional (on top of the trend) increase between 2010 and 2016/2017 in the value of homes within a kilometre of the tunnel. The researchers attribute this to the liveability benefits in the vicinity of the tunnel, which means that residents are more willing to pay for living in that zone. For the first 500 metre they found an increase of 7.1%, in the second 500 metre 4.2%. Every halving of the distance is associated with an increase in house prices of 3.5%. The study did not take into consideration new housing, existing homes further than 1 kilometre from the tunnel, and other types of real estate. At a distance of 1 to 2 kilometres, they found a total benefit of 500 million euros, but they could not attribute this with certainty to the tunnelling. Therefore, the researchers consider the measured liveability benefits of 220 million euros to be an underestimation.

The risk of an ex-ante welfare study is underestimation of the benefits due to quality of life, CPB concludes. The lesson that this example teaches is that the benefits from quality of life were estimated to a limited extent in advance. This is valuable information for economists who draw up a SCBA in advance, but for spatial designers it is a signal that significant added value of urban investment projects can be expected due to positive externalities in addition to travel time benefits for the users of the motorway. In retrospect, these turned out to be substantial; if the ex-ante travel time revenues are estimated at to more than 700 million euros, a realisation of 220 million euros is substantial. The actual measured benefits also include the additional benefits resulting from the construction of greenery on the tunnel roof in the project area itself. In this measurement, it is not clear what the individual components of the benefit sum are: which part of the 220 million euros is cleaner air, which part is eliminated traffic noise, and which part is the new park? Because the travel time benefits accrue to through traffic, the increased house value can be attributed entirely to liveability benefits. For spatial design, this means that silence (no car traffic), density, and greenery in the vicinity or integrated into the design (making the area car-free also saves a lot of space) creates social value and thus increases land value outside the direct project.

It shows that the Henry George theorem turns out to be valid in the case of the tunnelling of the A2 motorway near Maastricht. The tunnelling, including additional costs, appears to be beneficial to society on balance. The benefit is reflected in the land value around the project. It is precisely urban areas with high density that show benefits: the higher the density, the higher the benefits, because more people (homes) share in the benefits of the same investment. After all, the CPB study shows that extensive benefits arise for the large number of homes within a kilometre of the tunnel.



Figure 4. De Groene Loper, Maastricht: the tunnelling of the A2 contributed to the elimination of negative externalities like emissions and noise, and to positive externalities like the improvement of the living environment, higher value of existing housing and additional value of new housing development. [© Ballast Nedam / © Ballast Nedam, Aron Nijs]

RandstadRail Rotterdam-The Hague: Better accessibility and real estate development — A project with a similar higher than expected social benefit is the conversion of the former railway Hofpleinlijn into a light-rail connection between Rotterdam and The Hague (OV Magazine, 2018; Figure 5). The light-rail connection has more stations than the previous railway line; parts of it are below ground, part above ground; and it is crossing-free. In this project, it was not estimated in advance that the use of the old rail connection would bring positive externalities. The same applied to the exploitation. It turned out, however, that the number of travellers was higher than expected.

However, this higher-than-expected use is not a general phenomenon. The Netherlands Institute for Transport Policy Analysis (KiM, 2023) retrospectively analysed four public transport projects for their prediction and realisation of the use of public transport. This shows that estimates score variable and unpredictably regarding the difference between the estimate in advance and the actual use afterwards. This does not say anything about the positive externalities that occur in the vicinity of the new stations and about any additional new connections for existing stations. The starting point is that the travel time benefits of new high-quality public transport connections cannot be translated on-to-one to an increase in the value of homes in the vicinity of stations due to additional liveability benefits. Apart from purely economic issues, the external effects around public transport stations can be exploited by spatial designers.

The higher-than-expected use of the RandstadRail connection Rotterdam-The Hague may also have been caused by the interconnection of these two major cities in the Netherlands with each other and with the intervening suburbs, via the two large stations in large city centres. Various locations that house a large number of offices and thus attract commuters were now directly connected to each other. As a result, there are many transfer options to other public transport networks: international and national at Rotterdam Centraal station, national at Den Haag Centraal station, and regional and local in the immediate vicinity of these major stations by walking and cycling. Furthermore, the service is reliable because there are no crossings on the light-rail track, which increases the value of the service. This is beneficial for business travellers and commuters. In addition, good parking for bicycles has been provided at the stations.

The positive effect on the home value of the RandstadRail between Rotterdam and The Hague has been shown by Rodrigo et al. (2021), among others. These findings fit in with extensive literature on



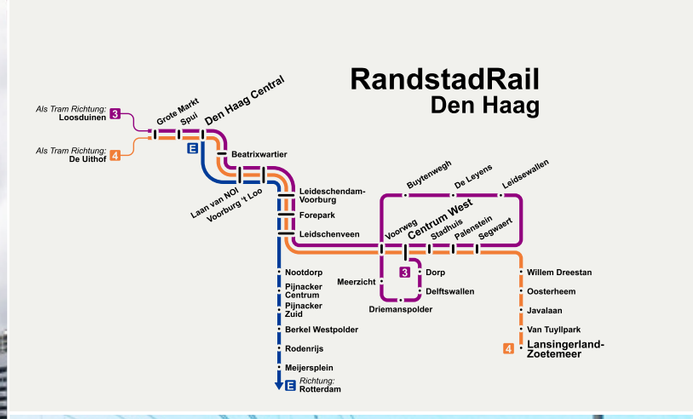




Figure 5. RandstadRail Rotterdam-The Hague: the light-rail connection serviced by Line E improves accessibility and number of travelers to the city centres of Rotterdam and The Hague. It also initiated housing and real estate development around new stations like Pijnacker Zuid, Leidschenveen, and Berkel Westpolder. [CC Florent Abel (left) / CC Wiesenpinguin (top right) / CC Michiel1972 (right)]

the higher land value (real estate value) in the vicinity of public transport stations. Van Oort (2024) showed that the ex-post benefits of the construction of RandstadRail can be divided into three categories, namely economic, liveability and social. All these three dimensions of well-being are positive, which does not always happen. Usually there is a trade-off between economic profit with disadvantages for people and the environment. [Transit-Oriented Development, page 114]

High-quality public transport systems in mass-density urban regions naturally have the potential for multidimensional social benefits, which are higher than the costs and which precipitate in the form of higher land value. The Henry George theorem predicts these higher-than-expected benefits compared to the costs. In the case of the realisation of RandstadRail Rotterdam-The Hague, this has not been established in an ex-post prosperity study yet. For spatial designers, however, the added value of public transport investments in urban areas is optimised by making beneficial use of positive externalities.

Area development RTHA site: Greater social potential than current use — The former Rotterdam Zestienhoven Airport, located on the outskirts of the city, was once intended for small (business) aircraft. Nowadays, Rotterdam The Hague Airport (RTHA) has become part of the urban area due to urban expansion and its use by aviation has been expanded with more and larger aircraft for predominantly European holiday traffic. The location close to the city, sandwiched between the A16-A13 motorways and the neighbourhoods of Overschie, Schiebroek and Lansingerland, leads to a major contradiction between the actual use and the potential for alternative use. The current use of the RTHA site for predominantly holiday flights means underutilisation of the land and generates negative externalities for the surrounding area, while there are no positive externalities for the surrounding area and Rotterdam as a whole. The site offers valuable opportunities for other pressing needs of residents of Rotterdam and the surrounding area. For example, the site is easily accessible from two metro stations of the RandstadRail (Meijersplein and Rodenrijs) suggesting that the site could also be used for housing.

A problem analysis showed that there is a lack of living space, greenery, forest, and space for water in Rotterdam and the surrounding area. For other functions, such as offices, there are no structural deficits that are at the expense of social welfare (Velleman & Turk, 2023). The study by Ziegler Branderhorst presents three future scenarios for the airport: continuing the airport in its current form, but as a business airport (only small air traffic), development into Pioniersbos, meaning airport closure and the creation of forest and greenery, and Stadskwartier Noorderbos, which also means full closure of the airport, after which the site will be used for homes, forest and water – including infrastructure, general facilities and social real estate (Branderhorst et al., 2024). In addition, the homes will be distributed according to the 30-40-30 rule among low, middle, and high incomes. The current buildings will be preserved as much as possible in the alternative plans – integrally designed by Ziegler Branderhorst – and given a new function. The current parking lots will be re-used in the scenario Stadskwartier Noorderbos (Figure 6). The new proposed city district makes use of the high relative value of homes in this easily accessible location (motorway and public transport) in the Rotterdam-The Hague Metropolitan Area, with positive external effects of greenery, forest, and water. Furthermore, value is created by the disappearance of noise pollution and by the integration of the surrounding urban fabric of Schiebroek, Blijdorp and Overschie in Rotterdam. The proximity and transport capacity of the Meijersplein and Rodenrijs metro stations will also be used. The housing construction (medium-high and low-rise single-family homes) will be mixed with social and commercial real estate based on the needs of Stadskwartier Noorderbos. This alternative has great social added value compared to maintaining the current airport (Branderhorst et al., 2024). The significance of Stadskwartier Noorderbos is in the use of the potentially substantial land value of the site itself, the disappearance of negative externalities on the environment (noise and air pollution), the application of positive externalities of greenery, forest and water, the proximity of public transport and a mix of functions in the spatial design.

In principle, much of the current activity will continue to exist, as not all activity is linked to aviation, but it is located there due to its location in the Rotterdam-The Hague Metropolitan Area. Activities connected to aviation may move to Schiphol. The effect on national prosperity is therefore zero. It can be assumed that the number of air passengers using RTHA (currently approx. 2 million annually) fits in the margin of the occupancy rate of the capacity of air traffic via Schiphol (approx. 65 million passengers) and other airports, such as Eindhoven Airport and Brussels Airport. Jobs that are important in the city district are important for the city district itself, but do not count for overall national prosperity. This does not mean that the activity in and around the city district is not important. It is, but the value of activity (facilities such as retail and catering) also appears in the house value. Moreover, labour market effects in an SCBA – of any intended investment – are no longer important. The reason is that the labour market is structurally extremely tight and that employment effects are national displacement effects.

From a spatial-economic perspective, the Henry George theorem predicts a high social added value in the event of area development of the RTHA site. High negative externalities in the surroundings of the airport are exchanged for positive externalities and alleviation of a constricted housing market, with substantial positive consequences for the land value of the site. The other possibilities have been explored in various spatial designs, which have been subjected to the most complete SCBA possible (Branderhorst et al., 2024). As an example, the current land use by RTHA yields annually dividends for the municipality of Rotterdam. This means that the rent from land is known

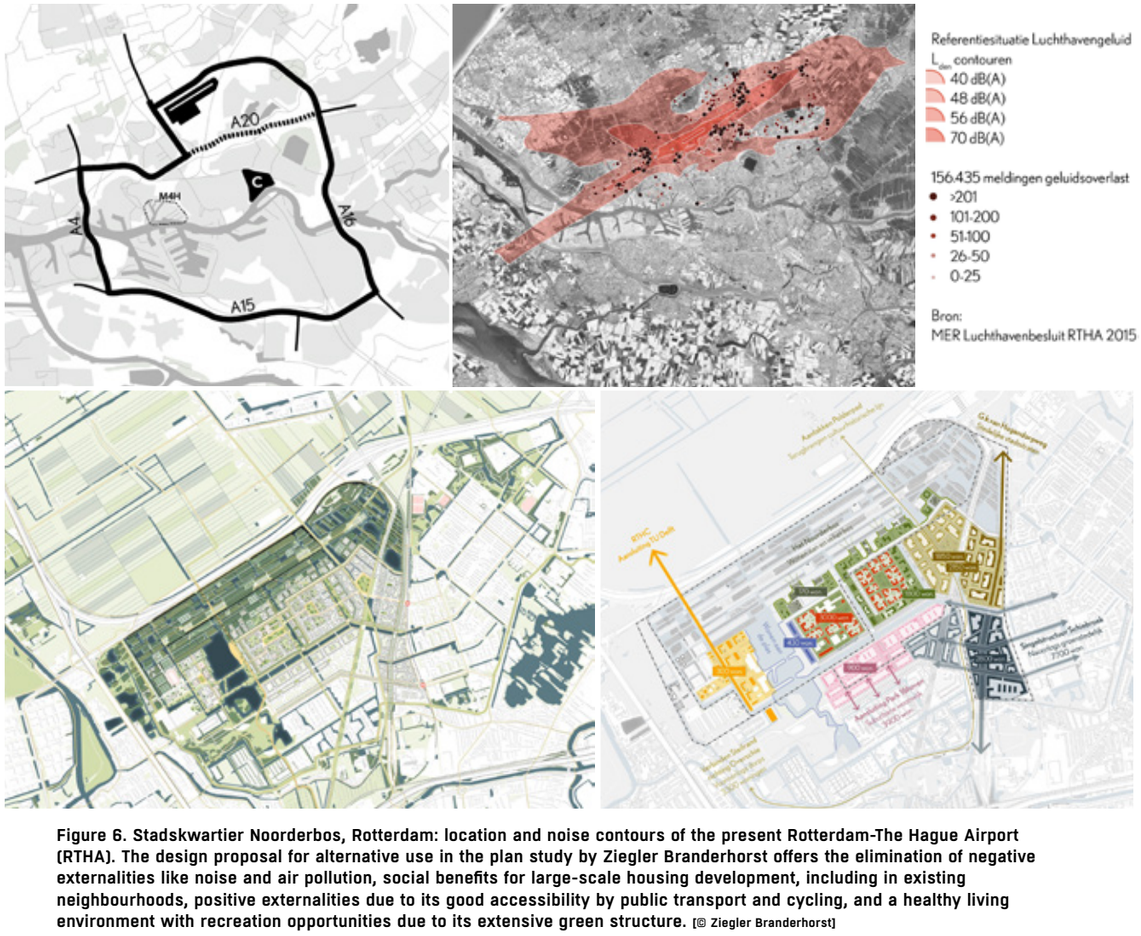


Figure 6. Stadskwartier Noorderbos, Rotterdam: location and noise contours of the present Rotterdam-The Hague Airport (RTHA). The design proposal for alternative use in the plan study by Ziegler Branderhorst offers the elimination of negative externalities like noise and air pollution, social benefits for large-scale housing development, including in existing neighbourhoods, positive externalities due to its good accessibility by public transport and cycling, and a healthy living environment with recreation opportunities due to its extensive green structure. [© Ziegler Branderhorst]

and therefore the price of the land. This is so low that alternative use for housing always leads to a higher land price if the purpose of the land is changed from airport site to building land for housing and associated functions. The tight housing market leads to that higher value. The possible objection 'there are more valuable effects' misses the crucial point: according to Henry George's analysis, such valuable effects have already been considered in the price of land for its current use via positive and negative effects. The conclusion is that, based on the yield of its current use, such effects do not exist to a sufficient extent.

What can designers and planners add in terms of value?

Before the value of a design of an infrastructure project is calculated by economists, it is useful in the design process if spatial designers and planners understand how economists look at value. After all, economists conduct an SCBA on the design. This contribution explains some concepts from economics that are important for spatial designers and planners so that they may create social value with the proposed project. Spatial designers and planners benefit from entering discussions with economists about the design of an infrastructure project at an early stage of the design process. This involves a few basic concepts from economics. These are:

- *Price and value*: value includes more than price.
- *Prosperity (wealth) and broad prosperity (wealth and well-being)*: there is more than just 'economic growth', for example clean air and water, biodiversity etc., and everything else that people value. Economists investigate this, but do not prescribe anything since value is the result of preferences chosen by people. Knowledge about what people value is important for spatial designers and planners: greenery in the vicinity, clean air and water, silence, biodiversity, history, etc. Research into house value shows this.
- *Externalities, positive and negative*: design is about avoiding negative externalities and creating positive externalities. This is also called *spillover*, such as from knowledge present within a university to companies on a campus. Positive externalities are the most valuable tool for the spatial designer and planner. For infrastructure projects aimed at transport connections, travel time is important, but new and easily accessible stations can attract additional passengers and stimulate housing and real estate development.

These concepts are important in the context of the analysis of markets in which effects occur. How are prices there affected by the project? Is there scarcity in, for example, a regional housing market, real estate market, or business parks? Are there structural shortages, which can make infrastructure projects useful, such as in the absence of natural value?

Impact assessment can be done in advance, but also after completion (as shown for the tunnelling of the A2 in Maastricht). Such analyses take into account the context of the nature of the goods or services involved: public goods, club goods, private goods, or natural resources. This involves awareness of the type of goods that the spatial designer is working on.

Finally, it is useful for spatial designers to consider for whom they design. Is it society, where the common good is concerned, or are there small but effective interest groups at the helm, or something in between? It is important therefore to also get a feel for political contexts. Of course, this will not be strange to designers, because design and value creation are touching economic and financial interests of particular groups (lobbies). Because it is ultimately about land value, an important theory about urban land value has been formulated: the Henry George theorem. It states that, at least in cities, positive spatial effects occur – the usefulness of which, including negative externalities, is fully and correctly reflected by the price of land. Landowners cannot escape this by moving to another location to avoid taxes, unlike labour and capital, which can freely move around.

With these concepts, the spatial designer and planner have an economic conceptual framework to design so that the neighbour's property can also increase in value.

Walter J.J. Manshanden, Netherlands Economic Observatory & Leo Bus, Policy analysis and interim solutions for transport and spatial issues

Notes

1. The social question is to what extent this is sufficient. The market fails to price such negative effects (these are not automatically included in the ticket price), and the government fails to draw up and enforce an effective permit system (anticipatory tolerance), so that the courts are often consulted.

2. In theory, this has a special consequence: it implies 'infinite' growth of cities, because every investment in the city as a collective good (or service such as a metro line) is on balance beneficial and leads to higher land values. The condition is that through investments, agglomeration advantages are constantly greater than agglomeration disadvantages.

REFERENCES ■ Aalbers, R., Renes, G., & Romijn, G. (2016). *WLO-klimaatscenario's en de waardering van CO2-uitstoot in MKBA's.* Centraal Planbureau & Planbureau voor de Leefomgeving ■ Adecs Airinfra & Rotterdam The Hague Airport. (2015). Deelonderzoek Geluid. In Rotterdam The Hague Airport (2015), *Milieueffectrapport Luchthavenbesluit Rotterdam The Hague Airport.* 44-50 ■ Alonso, W. (1960). A theory of the urban land market. *Papers and Proceedings of the Regional Science Association 6:* 149–157 ■ Alonso, W. (1964). *Location and land use.* Harvard University Press ■ Alonso, W. (1971). The economics of urban size. *Papers of the Regional Science Association 26*: 67–83 ■ Branderhorst, I., Van der Grind, H., Van den Berg, A., Manshanden, W., & Bus, L. (2024). *Ruim baan voor Rotterdam.* Bewoners Tegen Vliegtuigoverlast/ Stichting Urgenda ■ Buitelaar, E., Schilder, F., Bijlsma, L., & Bellaard, J. (2014). *De waarde van stijl. Een prijsanalyse van historiserende bouwstijlen.* Planbureau voor de Leefomgeving/Amsterdam School of Real Estate ■ Buitelaar, E. (2021). *De werking van de grondmarkt en de rol van de overheid. Verkenning en reflectie.* Planbureau voor de Leefomgeving ■ Daly, H.E., & Cobb Jr., J.B. (1990). *For the common good. Redirecting the economy towards community, the environment and a sustainable future.* The Merlin Press/Beacon Press ■ De Groot, H.L.F., Marlet, G., Teulings, C.N., & Vermeulen, W. (2010). *Stad en Land.* Centraal Planbureau ■ Dröes, M. I., & Koster, H.R.A. (2021). Wind turbines, solar farms and house prices. *Energy policy 155* (2921), 112327 ■ Ecorys, (2006). *Kengetallen Kosten-Baten Analyse project A2-Maastricht.* Ecorys ■ George, H. (1879). *Progress and Poverty.* D. Appleton and Company ■ Hooimeijer, P., Kroon, H. J. J., & Luttik, J. (2001). *Kwaliteit in meervoud; conceptualisering en operationalisering van ruimtelijke kwaliteit voor meervoudig ruimtegebruik.* Wageningen Environmental Research ■ Lijesen, M., Van der Straaten, W., Dekkers, J., & Van Elk, R. (2006). *Geluidsnormen voor Schiphol; een welvaartseconomische benadering.* Centraal Planbureau ■ Lubbe, M., De Boer, L., Marlet, G., Koopmans, C., & Willebrands, D. (2011). *Maatschappelijke kosten en baten van verschillende verstedelijkingsstrategieën tot 2020.* Planbureau voor de Leefomgeving/Atlas voor gemeenten/SEO ■ Luttik, J. (2000). The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape and Urban Planning, 48* (3), 161–167 ■ OV Magazine (5 juli 2018). *RandstadRail nu hét voorbeeld van light rail.* Retrieved from: https://www.ovmagazine.nl/nieuws/randstadrail-nu-het-voorbeeld-van-light-rail ■ Rho adviseurs voor leefruimte & Rotterdam The Hague Airport. (2015). *Rotterdam The Hague Airport. planMER.* Rotterdam The Hague Airport (RTHA) ■ Reich, R. (2019). *The common good.* Vintage Books ■ Rodrigo, J., Van Oort, F., & Terlien, E. (2021). Waardestijging van woningvoorraad door Randstadrail. *Economische Verkenning Rotterdam 2021*, 74-77 ■ Romijn, G., & Zondag, B. (2012). *Het nulalternatief voor KBA's van grote gebiedsgerichte projecten. Een verkenning op basis van de casus Schaalsprong Almere.* Centraal Planbureau/Planbureau voor de Leefomgeving ■ Rouwendal, J., & Van der Straaten, J. (2008). *The costs and benefits of providing open space in cities.* Tinbergen Instituut (TI) ■ Teulings, C. & De Groot, H.L. (2020). Zuidasdok: nut en noodzaak. In Dekker, S. (2020), *Voortvarend bouwen aan de toekomst. Verkenning van de nut en noodzaak, mogelijke optimalisaties en versoberingen van het project Zuidasdok in het licht van de spanning tussen scope en budget.* Amsterdam/Den Haag, Bijlage III ■ Tijm, J., Van Maarseveen, R., & Michielsen, T. (2018). *Leefbaarheidsbaten A2 tunnel Maastricht zeer aanzienlijk: meer dan 200 miljoen.* Centraal Planbureau ■ Van Gent, D., Vegter, S., Van der Zaan, T., Roosendaal, G., & Lageveen, M. (2021). *Quickscan onderzoek financiële kosten en opbrengsten gebiedsontwikkeling. Een vergelijking tussen ontwikkelingen op binnenstedelijke en uitleglocaties.* Decisio/ Fakton ■ Van Oort, F. (2024). *Meervoudige waardecreatie en brede welvaart bij infrastructuurprojecten in de MRDH.* Real Estate Research Quarterly ■ Velleman, J., & Turk, F. (2023a, mei). *Stand van zaken Kantorenmarkt 2023. De belangrijkste ontwikkelingen op nationaal en provinciaal niveau.* Retrieved from: https://www.nvm.nl/media/wrzfaj5s/stand-van-zaken-kantorenmarkt-2023.pdf.

LESSONS

DESIGNING FOR THE LAND VALUE OF THE NEIGHBOURS

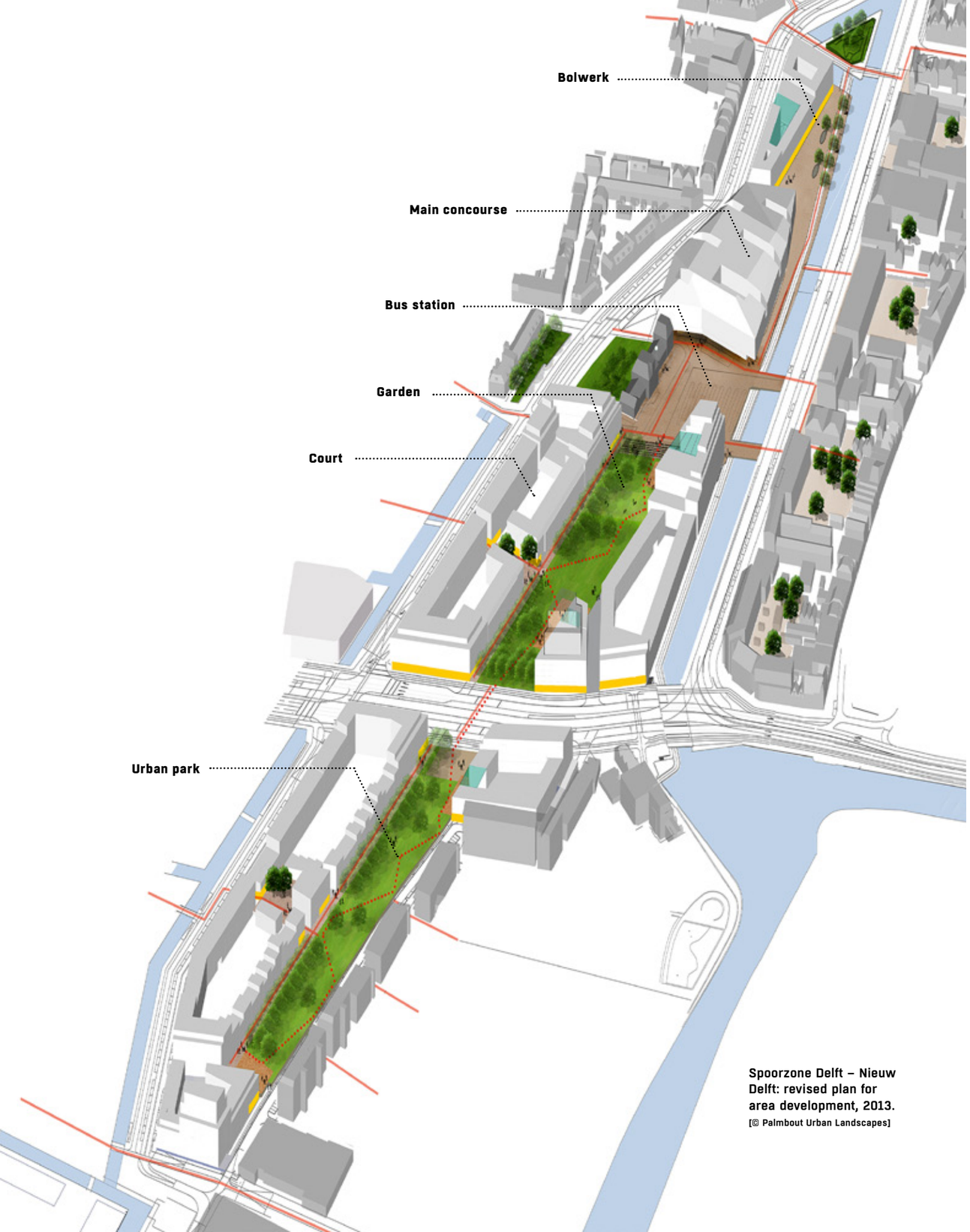
Although there are many lessons to be learned from numerous examples, four are mentioned here:

- ***Take into account land price in the design process: substituting land with land price as a guideline in large cities by definition provides social added value.*** In urban areas, think from the point of view of the price of land, the factors that explain the price, and the associated theory. For nature and hydraulic engineering outside big cities, such a theory does not exist, so that the value can only be approximated through design and calculation.

- ***Benefits can turn out to be more favourable than calculated in advance.*** The lesson can be learned that the benefits can be much more favourable than calculated in advance. In the case of RandstadRail, the use was higher than previously estimated, which brings general benefits, such as higher house values.

- ***Design from a broad prosperity perspective.*** Take into account proximity, density and mix of functions and positive spatial external effects of, for example, play and meeting opportunities, greenery for biodiversity and cooling, etc. As such, design concerns all economic, social, ecological, and cultural-historical values (Hooimeijer et al., 2001). Be aware of negative externalities and try to avoid them as much as possible in the design or propose compensatory measures.

- ***Consultation between designers and economists at an early stage of the design process contributes to the quality of the design and the choices made in it.*** The last lesson, but not the least: think about who you work for, and what kind of good or service it is: collective or private? And what does the design do for well-being and natural resources?



Spoorzone Delft – Nieuw Delft: revised plan for area development, 2013.
[© Palmbout Urban Landscapes]

SPOORZONE DELFT

BRIDGING THE GAP

As a medium-sized city, Delft embarked on a great adventure to build a new railway tunnel along its historic city boundary. A major intervention, which should both remove an urban barrier and provide conditions for the development of a new city district. How to get such a large infrastructure project and area development off the ground in a coherent way? How to finance and manage such a project? What is the role of the municipality? Should the city be locked down at the costs of inhabitant's daily activities? Can infrastructure development be seen separately from urban development at all? How can the allocation of risk be organised in such a way, that it does not make the parties involved shy away from necessary innovation, but jointly look for social value creation for future generations? These are all questions to which the municipality of Delft has had to find an answer.

Delft is located on the busy Rotterdam – The Hague railway line, opened in 1847. The railway line was located at ground level just outside the centre of Delft. Parallel to the railway was the waterway Rotterdam – The Hague. After the arrival of the railway, Delft began to build houses over the railway. The combination of a busy railway line and a waterway became an increasing barrier for crossing traffic (Figures 1–3). In the 1960s, it was therefore decided to fill in the waterway and build the railway on a viaduct. The municipality of Delft was so happy with the chosen solution that it helped pay for the construction. This solution had worked well for many years. However, train traffic continued to increase and so did the noise created by those trains. Noise pollution became an increasing problem for the growing city. It made the construction of new homes near the railway increasingly complicated because noise standards were exceeded. The viaduct also started to function as a social barrier. Although the viaduct could be crossed over the entire length of the railway line, it still felt like a dichotomy in the city. Cars were parked under the low viaduct and the shortcuts to the city centre were narrow and dark. Furthermore, the railway line and the train station could no longer cope with the growth in the number of passengers and trains. It was time for a new station, more tracks and much less nuisance. If the noise caused by the trains could be resolved, the city could also start building houses close to the tracks again. This formed the seed of the Spoorzone Delft project. The project has grown into the construction of a new train station with a bicycle shed for 10,000 bicycles, a four-track tunnel of 2.3 km, 1,000 homes, office space, public facilities, a city park, the municipal office, and a new tram/bus station. How did a medium-sized city manage to make such a large project a success?

The intertwining of infrastructure and area development

The Spoorzone project contains two major components: the Willem van Oranjetunnel – a large infrastructure project – and area development around and above that tunnel. The construction of the infrastructure is the responsibility of the national government; the realization of the area development had to be done by the municipality of Delft. Both components are closely intertwined. They take place in the same physical space, and the municipality planned to use the financial proceeds of the area development to pay for part of the infrastructure. How to deal with such interconnectedness and interdependence in planning and decision-making?

Putting the assignment on the agenda — In 1988, the Dutch Railways (Nederlandse Spoorwegen – NS) presented the Rail21 plan. Rail21 was a vision of the future of the Dutch rail network in the 21st century. The plan proposed to significantly expand the rail infrastructure and add more trains to the timetable. This allowed rail use to compete better with the growing car traffic. The

most important railway lines, including the railway line The Hague – Delft – Rotterdam would be quadrupled in size. The municipality of Delft, however, doubted whether a four-track route right through Delft was desirable and possible. A year later, Palmbout Urban Landscapes showed what was possible above ground in terms of area development if the railway was placed in a tunnel. In 1993, TU Delft compared variants of track doubling by Delft. These variants were: (a) a second viaduct next to the existing viaduct; (b) a two-track tunnel – retaining the existing viaduct – built via a pit for a bored tunnel; (c) a four-track tunnel built via an excavation. The conclusion was that the four-track tunnel was by far the best solution. This solution would cause the greatest disruption during construction, but the new situation would be a significant improvement. In the following years, the municipality of Delft propagated the vision of Rail21 and continued to put this solution – the railway tunnel in combination with area development – on the agenda.

Planning and decision-making – The real planning process could only begin in 2002, when agreement was reached with the province of South Holland and the national government on the need for a railway tunnel and the first national government contributions for the investment were promised. The municipality of Delft was also willing to contribute to the costs. A separate development organization, Ontwikkelbedrijf Spoorzone (OBS) was set up, and the study could begin. A small group of people worked exclusively for OBS, while expertise was deployed from the civil service organization. Although the track doubling was the responsibility of the central government, the municipality of Delft was the driving force behind the plan preparation. During the design phase, there was close cooperation between the national government, the NS as the national railway operator, and ProRail as the implementing organisation for railway development and management. These parties have the knowledge about the rail infrastructure, and the central government had a decisive say in the project.

OBS ensured that other projects, which the city also considered desirable, were only added to the project if these plans had a strong connection with the Spoorzone project. This keeps the focus on the main task and on coherence between all connected projects. The renowned architect and urban planner Joan Busquets was commissioned to design the public space (Gemeente Delft, 2003). In doing so, the city was opting for a high level of ambition. The intervention in the city was therefore also called, the project of the century. The disappearance of the massive, ugly railway viaduct would be a huge improvement in quality for the city. The project team created a series of documents that were necessary for decision-making: a masterplan, an environmental impact assessment (MER) of the Spoorzone (Witteveen+Bos, 2003), and a zoning plan (Gemeente Delft, 2005).

At the same time as the plan development, the municipality of Delft was looking for additional funding for the project. Since the railway line was infrastructure implemented by the central government, it was logical that it pays most of those costs. The previously promised funds were completely insufficient to cover all costs. National support for the project was not stable during the life of the project. The then Ministry of Transport, Public Works, and Water Management (Ministerie van Verkeer en Waterstaat – V&W) doubted about the need for two extra tracks. The financial resources of the government were limited. If a tunnel with four tracks would not be necessary, the four-track tunnel will become "the most expensive noise barrier in Europe", according to the ministry. The municipality was trying to refute this argument and asked TU Delft to investigate whether a reliable timetable could be made with the desired number of trains in the future. This turned out not to be feasible with two tracks. International trains and a single freight train require so much space in the timetable a regular timetable would be impossible. The Ministry of Housing, Spatial Planning, and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer – VROM) at the time did see great added value in the project. In the Spoorzone Delft project, a direct link was made for the first time between a large infrastructure project and



Figures 1-3. The railway control station and Michielsbrug over the Westersingelgracht in the second half of the 19th century with the houses on the Spoorsingel in the background, 1930. / The daily hustle and bustle around the level crossing opposite Binnenwatersloot and Spoorsingel, 1960. / The former level railway and waterway on Spoorsingel with windmill De Roos on Phoenixstraat in the background, circa 1950. [PD Stadsarchief Delft, Municipal police (top-right)]

area development. Building more homes in the city centre was highly desirable, but this would only be possible if the trains ran in a tunnel. If this project would succeed in Delft, this solution could also work for other cities with a similar task. The Ministry of Finance found the financial arrangement interesting, in which both the municipality and the project developers contributed to the costs of the tunnel with part of the expected profit from the urban development. Such a public-private partnership (PPP) had never been successful in the Netherlands before.

On 1 November 2004, all signals were green. The Minister of Transport, Public Works and Water Management decided that the Delft railway tunnel would be built. However, the discussion whether the railway tunnel would have two or four tracks was not yet finished. A compromise was found: a tunnel would be built that could accommodate four tracks but containing initially only two operational tracks.

A year later, on 5 October 2005, the contracts were signed. Both the ministries of V&W and VROM contributed to the costs, as did regional governments and the municipality of Delft. The contribution of the project developers was also recorded. The risk that the project developers would pay less was borne by the municipality of Delft. The contracts contained a striking condition: the municipality of Delft would oversee the area development *and* the construction of the railway tunnel. All risks of cost overruns therefore lay with the municipality. For Delft, this was the reason to enter the discussion with V&W to amend this decision after signing. The railway tunnel was infrastructure that fell under the responsibility of the central government, so the responsibility should therefore lie with the central government. Indeed, the government took back control of the construction of the tunnel and agreements were made about the distribution of the risks. [Risk Assessment, page 198]

Spoorzone Delft as an integrated spatial and infrastructural design

The location of the railway tunnel was already more or less determined at the start of the design process. There were so many spatial preconditions, including the preservation of (historic) buildings, that only one route was possible: the railway tunnel would be located directly next to and under the existing railway viaduct. The exact location could only be moved a few meters at most. How could an ambitious design be realized with such limiting spatial factors?

Northern part: Phoenixstraat — Phoenixstraat is the northern part of the route. Here, the railway was located on the viaduct. There were approximately 450 parking spaces under the viaduct for residents and visitors to the centre. There was a great desire to excavate the historic city canal, which was filled in for the construction of the railway viaduct. This made it impossible to bring back all 450 parking spaces above ground. A double-storey car park next to the tunnel and under the canal was the best solution in this situation. With these plans, almost the entire underground cross section of Phoenixstraat would be filled by the railway tunnel, canal, and car park. It turned out to be possible to build more than 450 parking spaces underground.

The Spanish urban planner Busquets designed the public space. On the side of the city centre, space was created for outdoor cafes, pedestrians, and cyclists. The other side of Phoenixstraat with residential buildings has become a car-free area. The tram and the main road were in the middle of the cross-section planned. Both were designed to be as ‘green’ as possible. Special buildings were accentuated with different pavement. The traffic infrastructure was designed as ‘soft’ as possible. Where possible, trees have been added. Given the shallow depth of the tunnel, it was quite difficult to find places where trees have sufficient ground cover.

Middle part: Station square — The station area is the middle part of the route. In this area, many homes and businesses were demolished to make the construction of the station and the municipal office possible. The existing station building, a national monument from 1885, has been preserved. The houses on Van Leeuwenhoeksingel were on the same building line as the now defunct station. Two variants were therefore: a route with and without the demolition of the buildings on Van Leeuwenhoeksingel.

Several locations were investigated for the location of the train station. There was a great desire in the city council to place the new station as close as possible to the city centre, with the

Bolwerk location as the ideal place. It was quickly concluded that this would not physically fit. A second location – near Westlandseweg – was further investigated. In this situation, the station would be easily accessible for car and bus traffic. If a short railway tunnel would be built, the station itself could be built above Westlandseweg. In the end, the variant was chosen in which the underground station was built close to the current station.

Given the large volume of traffic flows, it was decided to physically separate all modalities. Private traffic can reach the station via Coenderstraat – the east side of the station – and public transport via the west side, at Westvest. The cycle routes were laid out below ground level. A conflict-free cycle route to the TU Delft campus was constructed. Barbarasteeg was used a lot for cyclists and pedestrians but was much too narrow for that: less than 2 metres wide. In the design, the cycle route via Barbarasteeg was made unattractive by creating detours.

The first underground bicycle shed with 5,000 spaces was placed directly above the train platforms, with several direct connections to the platforms. It is possible to reach the bicycle parking spaces by bicycle. Thus, the bicycle shed has become the best place to park your bicycle and walk to the platforms. All other locations in the station area are further away from the platforms. The result is that no bicycles are placed at random on the station square, so little enforcement is needed. At the beginning of the design process, only about 3,000 bicycles were parked at Delft station at any one time, so that it was expected that a parking facility with 5,000 spaces would be more than sufficient, but this was not the case. The university, train traffic, and the use of bicycles to travel to the station grew much faster than expected. At the start of the construction of the railway tunnel, there were already more bicycles around the station than would fit in the future parking facility. Together with the builder, a place was sought for a second bicycle shed and a third after completion of the project. There are now about 10,000 bicycle spaces available and that number is still not enough. An underground place for a fourth parking facility is not easy to find. The solution is sought in removing bicycles parked for too long, or perhaps to introduce paid bicycle parking for bicycles that are parked for longer, and in making the Delft Campus suburban train station more attractive, by making more trains stop at Delft Campus station and expanding the bicycle shed.

Southern part: Area development — No development plans were drawn up for the variant with a short railway tunnel. The southern part consists of a large area that has been fallow for years. The area was used as a business park but was no longer suitable for this due to its location in the middle of the city. Housing construction was not possible due to the noise nuisance from the train. With the first ideas for a railway tunnel, it was clear that this area would have great potential for housing if the nuisance caused by the train could be resolved. A long railway tunnel offers that solution. The location of the southern part of the railway tunnel was simple. The constraint points of the existing track and the new station building were fixed, which means that only one route was possible: a straight line that connects these two constraint points.

The extra costs for the longer tunnel could be partly covered from the profit that could be made in the area development. The contribution of the landowners was laid down in an agreement and linked to a housing programme for each sub-area. The layout of the area was then made under the direction of OBS and Busquets in close consultation with the project developers. Palmhout Urban Landscapes made a less complicated design plan that was easier to realize (Palmbout Urban Landscapes, 2013; Figure 4).

It was explored whether it would be possible to build buildings on the railway tunnel. Technically that would be possible, but it would then have to be clear when designing the railway tunnel which building would be built where on the tunnel. That was judged too complicated. Since the area development also needs a park, placing the park on top of the tunnel was considerably easier. The park is now on top of the tunnel and the houses are built next to the tunnel. The municipality has explored whether an even longer tunnel would also be realistic. This could solve the physical barrier effect of

the southern part of the railway line. The alternative of an extra-long tunnel was dismissed because this would have been even more expensive without any additional revenues. The site south of the chosen tunnel is a well-functioning industrial site that is not affected by the noise nuisance created at the transition from the tunnel to ground level. [Benefit-Oriented Design, page 276]

How to carry out a large-scale intervention without the city coming to a standstill?
The integrated spatial and infrastructural design for the railway zone contains many functions, affects multiple systems, has different scales, and therefore has many interdependencies. Multiple sectors and specialisms were needed that must work well together. In addition, the important railway connection of the western Randstad must continue to function, as must the city of Delft for the long period associated with such a large-scale intervention. How was all this managed?

The tender — The construction of the railway tunnel and station and the layout of the public space were put on the market as a single project. As infrastructure provider, ProRail oversaw this because the railway tunnel was the main task. The new municipal office forms a coherent whole together with the train station because it is in the same building. The municipality put the municipal office out to tender. The builder of the train station was given requirements that were necessary to be able to build the municipal office. The municipal office is partly on the location of the old viaduct tracks. That part of the municipal office could only be built when the trains run underground. An attempt has been made to build as much of the municipal office as possible at the same time as the railway tunnel. In the end, it turned out that about 80% of the municipal office could be built at the same time as the station.

The municipality of Delft and ProRail have a different method of tendering. ProRail works with a system of specifying the conditions that the railway tunnel must meet. The municipality asked Busquets to make a design for the public space and searched for a contractor to carry it out. Since ProRail is in charge and the railway tunnel is by far the largest project, ProRail's working method was used for the tender. The municipality described the Busquets plan at the level of 'must have' and underlying requirements, so that it would fit in with ProRail's system. The Busquets plan was added as an appendix with the explanation that the design meets all the requirements. The contract form for the tunnel was design and construct (D&C). [Procurement of Infrastructure, page 102]

Four parties made bids for the construction of the railway tunnel and the layout of the public space. One party offered to conduct the project in its entirety. Other parties were a combination of parties. A team from ProRail, the Ministry of Transport, Public Works and Water Management and the municipality of Delft evaluated the bids of the four parties against the set requirements. None of the evaluators knew for what amount the parties had quoted. For the municipality of Delft, the focus was on the layout of the public space, the car park under Phoenixstraat-Spoorsingel and the construction phasing. The construction time of the tunnel was estimated at about 10 years. Phoenixstraat and Westvest together are the main access to the western part of the city centre, and the route must be maintained if the railway tunnel is built. The train station and the local and regional public transport together form the heart of the public transport system. During the construction period, the municipality wanted to retain a well-functioning station, both for tram and bus. The buildings along the railway route are monuments and of great historical value and must not be damaged during construction. Despite these requirements, the construction phasing seemed to be of secondary importance to the applicants. For them, the tunnel was the main task, and none submitted a well-developed plan for the construction phasing. This meant that the municipality, ProRail, and the chosen construction consortium Combinatie CrommeLijn (CCL) still had a lot of work to do after the contract was awarded in order to arrive at a working construction phasing. As a result, the project was delayed right at the beginning of the implementation. [Life Cycle Management, page 98]

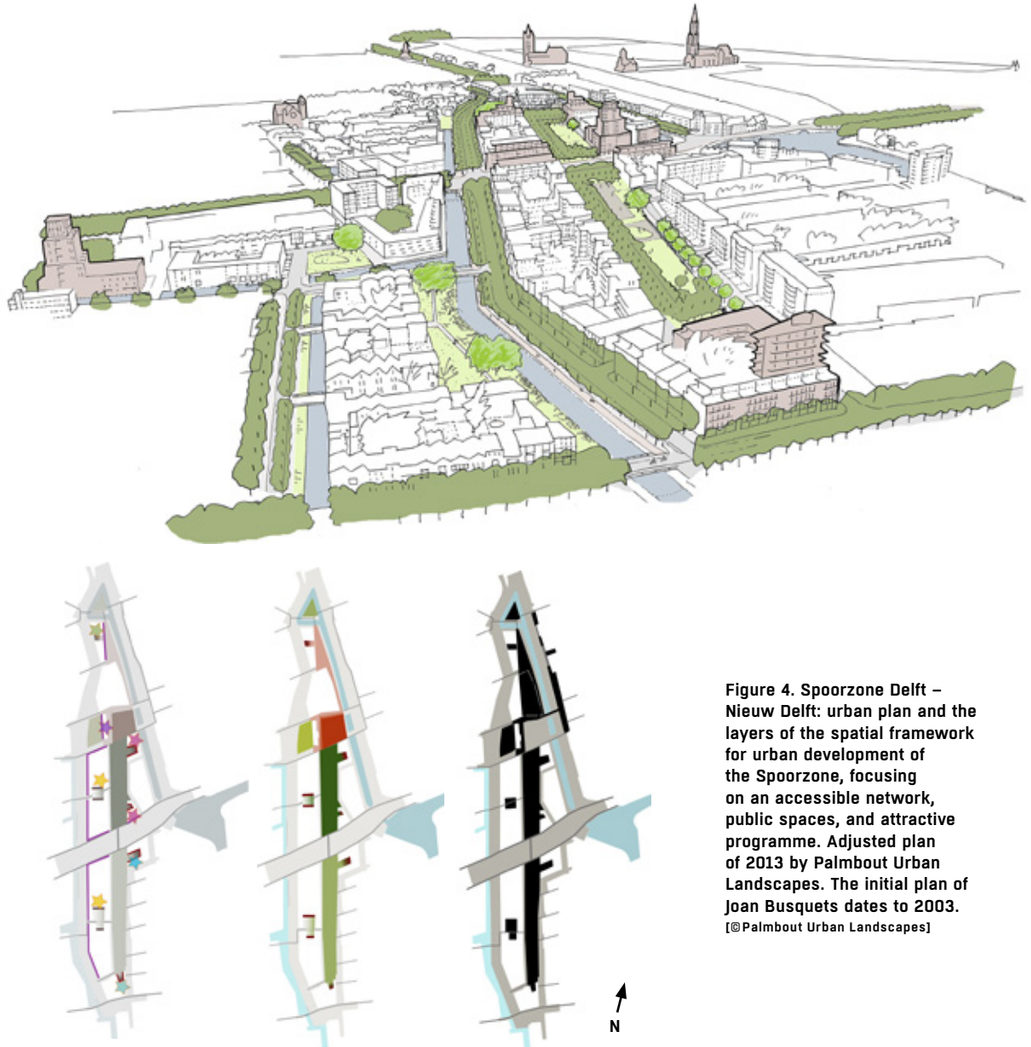


Figure 4. Spoorzone Delft – Nieuw Delft: urban plan and the layers of the spatial framework for urban development of the Spoorzone, focusing on an accessible network, public spaces, and attractive programme. Adjusted plan of 2013 by Palmbout Urban Landscapes. The initial plan of Joan Busquets dates to 2003.
[©Palmbout Urban Landscapes]

The construction phase — ProRail, OBS, the municipality of Delft and CCL jointly set up a project group that designed all construction phases and interim adjustments to that phasing. ProRail and OBS were the independent chairs of this group. Together, the group members had sufficient knowledge of civil engineering, traffic engineering, process management, and environmental management. All intermediate phases were discussed with the emergency services. For the emergency services, the accessibility of the entire city, the construction site and of all buildings along the construction site were important. The group was instructed to produce solutions without considering the question of which party was responsible. The discussion about the distribution of costs was conducted in another legally oriented group. [Project Management for Integrated Infrastructure Design, page 106]
The main goal of the construction phase was to ensure that the traffic system, for all modes of transport, functioned as well as possible with as few road closures as possible. The lack of space was the biggest problem. The priority order for distributing the scarce space was: 1. emergency

services, 2. bicycles, 3. local and regional public transport, 4. pedestrians, and 5. car traffic. In practice, this meant that car traffic was given only one lane in each direction and there was no room for parking in Phoenixstraat and on the station square. For public transport, a temporary bus station was chosen that did not have to be moved during the entire construction period. The temporary new bus station was larger and clearer than the old bus station. In fact, bus passengers had a better bus station than the old bus station ever had been.

The situation for cyclists was far from ideal. An important cycle route from Delft-West through the Abtswoudse cycle tunnel to TU Delft was blocked for a long time. The bicycle tunnel itself could be used, but the space – just over two meters between the cycle path and the construction pit of the railway tunnel – was too tight for a safe bicycle route. A (steep) staircase for pedestrians would still fit, but the expectation was that more than 10,000 cyclists would use it because otherwise they would have to cycle a big detour. Other cycle routes could remain in use by allowing cyclists to cycle through sea containers. It was then possible to build safely above the sea containers. The location for temporary bicycle parking was close to the train station, but the number of spaces (5,000) was far too few for the number of bicycles looking for a space. Bicycle parking remained a major task throughout the construction process.

The traffic light controls were an important part of the construction phasing. Access to the construction sites was partly regulated by traffic lights; for emergency services, possibilities were built into the scheme to clear the approach route of car traffic in time.

In Phoenixstraat, a cut-and-cover method with slurry walls was chosen to build the tunnel (Figure 9). The idea was that as soon as the roof of the tunnel had been installed, the above-ground space could be immediately used again for road diversions or parking, while further digging and construction could take place underground, making it essentially a cover-and-cut method. That turned out not to be possible. The tunnel roof was not yet strong enough to support above-ground traffic because the walls separating the tunnel tubes had not yet been built.

The residents of Delft were asked annually to give an opinion on the construction phasing with an open question for any suggestions for improvements. All modes of transport were given a positive judgement during the entire construction period. The open question generated hundreds of responses and suggestions for improvement.

The 2008 financial crisis — When concluding the contracts with the project developers, times of boom and bust of the economy were considered. It was expected that both would occur several times over a development period of thirty years. An economic downturn would have financial consequences for part of the project, but such a loss could be (partially) made up for in a phase of economic boom. With the bankruptcy of Lehman Brothers in 2008 an international banking crisis was a fact. Confidence in the financial markets globally was completely gone and banks had to be kept afloat by governments. This crisis had major consequences for the real estate market and therefore also for the area development of the railway zone. The business case for the area development became heavily negative. The expected profit from the area development was much lower than forecasted, and therefore not enough money was available to invest in the tunnel. That bill was paid by the municipality, which had no way to reduce the financial risks. A regular area development can be halted to stop spending. In the project, halting the construction of the tunnel was not an option. So, the expenditure continued and the income from the area development did not materialise. The crisis could not have come at a worse time. The designs for the first houses to be built had already been made and could be put on the market. This large financial loss has still not been made up during the development period. The city has had to make severe cutbacks in various public services to become financially healthy again. Such incidental setbacks can be eliminated over a long term, but the interests are structural and multi-year in nature.



Figures 5–8. The busy and noisy railway line from the sixties cutting through the city. [CC Stadsarchief Delft, Ton de Ruiter / PD Steven Lek] / **Former platforms Delft station. The last train has just left in the night of 21 to 22 February 2015.** [Jan Nederveen] / **Figure 9. Construction works for the underground railway and station.** [© Ronald Tilleman Photography]



The last steps to completion

In the night of 21 to 22 February 2015, the last train ran over the railway viaduct (Figures 5–8). In a week's time, the railway tunnel was connected to the railway network. On 28 February, the first train ran through the tunnel. After that, the demolition of the railway viaduct and the final layout of Phoenixstraat started immediately. In 2015, the effects of the financial crisis were not yet over. The area development of Spoorzone Delft was not yet realised. To help get the area development going, the first hundred homes in Coenderstraat were put on the market for a mix of clients. Three project developers, two residents' collectives and thirty-seven private clients were the first pioneers in Coendersbuurt. An 'image quality' plan – inspired by the historic city centre of Delft – was the basis for the architects' designs. It resulted in a neighbourhood with a wide variety of shapes that together form a whole. Construction of the first homes started in 2016 and five years later Coendersbuurt was completed. By 2017, the final crisis was over and the regular area development, now called 'Nieuw Delft', started. In 2025, three-quarters of the area was built up.

Spoorzone Delft has delivered a well-received and well-functioning station and an attractive neighbourhood. The nuisance caused by trains is gone. The gap between the city centre and the adjacent neighbourhood has been bridged. The real estate value of existing buildings around the railway zone has risen more sharply than the average market development because of the tunnel (Van Ruijven & Tijm, 2023). The appreciation for Spoorzone Delft among residents and professionals is high, but unfortunately so is the financial burden on the municipal budget.

Jan Nederveen, Municipality of Delft

REFERENCES ■ Gemeente Delft. (2003). *Masterplan Spoorzone. Masterplan op basis stedenbouwkundige visie Joan Busquets.* Gemeente Delft ■ Gemeente Delft. (2005). *Delft, Spoorzone. Bestemmingsplan.* Gemeente Delft ■ Palmbout Urban Landscapes. (2013). *Nieuw Delft – City Lounge, Openbare ruimte en stedelijk programma.* Palmbout Urban Landscapes ■ Van Ruijven, K., & Tijm, J. (2023). *Leefbaarheidseffecten van integrale infrastructuurprojecten: inzichten uit onderzoek.* Centraal Planbureau (CPB) ■ Witteveen+Bos. (2003). *Milieueffectrapportage (MER) Spoorzone Delft.* Gemeente Delft.

LESSONS

BRIDGING THE GAP

With today's knowledge, the municipality of Delft would start such a project again, but keeping in mind the next lessons:

- ***Idea and project definition should be paired with lobbying.*** A good project has a strong substantive line and a lobby line. The substantive line works on the design and prepares the decision-making. The lobby line seeks regional and national support and funding for the project. The substantive line should not wait until funding has been arranged, because the financiers want to see a fully developed project. [Stakeholder Analysis, page 112]
- ***The distribution of financial risks must fit the financial capabilities of involved governmental bodies.*** No project can withstand a rare international financial crisis. For projects with a lead time of 20–30 years, the chance that such a crisis will occur again is conceivable. It was a good idea to invest the expected profit from the area development in the railway tunnel, but the risk of a large loss should partly lie with the national government. If the national government does not want to take on part of that risk, it will be even more complicated to start future projects because municipalities cannot bear these major risks.
- ***The organization and impact of the construction phase must have high priority and already be addressed at the tender stage.*** In projects with a long construction time in a complex environment, good construction phasing is a precondition for success. Only thinking about the construction phasing after the award immediately leads to a delay in construction.
- ***Anticipate to large traffic flows and their potential growth during the construction phase.*** A large train station always has large traffic flows. In temporary situations, these traffic flows require a lot of space. Dimensions that are too tight during the construction phasing lead to unsafe situations and a poorly functioning traffic system. Design for capacity and stability of the traffic situation during the construction phasing. Consider future growth in traffic volumes.
- ***The subsurface needs spatial planning and cables and pipes must part of the design.*** The subsurface in a highly urban area is full of cables and pipes from many different owners. Ordering the pipes in the subsurface should be part of the design.
- ***Pay attention to maintenance and adaptivity for the long term from a life cycle perspective.*** Will the railway tunnel still function well in 2125? In a hundred years' time, the railway tunnel may need major maintenance or there will be capacity problems on the track or the station. The project did not consider whether the tunnel and station could be thoroughly renovated without disruptions or a full closure.
- ***Separate legal interests from civil engineering solutions during the construction phase.*** A project group of builders, municipalities and clients that is specifically focused on making the construction phasing and solving bottlenecks during the phasing, without considering about which party bears the costs, is effective. A substantive solution to a bottleneck is found much faster this way. The question of whether that solution can be cheaper can therefore be answered.
- ***Develop an image quality plan as framework for the design of houses and buildings.*** This is a powerful tool to achieve unity and diversity in the housing and office blocks. Go for quality. What is being built now will remain in place for 50 to 100 years.


Delft
Delft

FEATURED DESIGN: SPOORZONE DELFT

URBAN DEVELOPMENT BY INFRASTRUCTURAL INTERVENTION

An infrastructural intervention can make or break a city. The railway, bordering the center of the historic city of Delft, was for over a century an urban barrier and environmental burden. Despite the financial crisis during its development, Spoorzone Delft – with its railway tunnel and urban transformation – brings a new future for the city.

Characteristics

An elevated railway viaduct with two tracks has run along the historic city center since 1965. Every day, 350 trains ran on these tracks, causing extreme environmental nuisance. Furthermore, the station and the railway could no longer cope with the growth in passengers and trains. To the south of the station, an area of 24 hectares was located, with a mix of industrial buildings, homes, and fallow land near the railway tracks. From 1988 onwards, the first plans were made for a four-track railway tunnel to solve the capacity problem, and to redevelop the area. It was not until 2002 that sufficient political support could be gathered to develop this major project, based on an urban design which was adjusted in 2013. For the first construction phase, the Spoorzone project comprised:

- A railway tunnel with a length of 2.3 km prepared for four tracks.
- An underground train station with the municipal office of Delft on top.
- An underground bicycle shed with initially 5,000 and eventually 10,000 spaces.
- A parking garage parallel to the railway tunnel with 650 parking spaces over two floors.
- Approximately 1,000 dwellings, some including office space, and 25,000 m² of dedicated office and meeting spaces.
- A tram and bus station.
- A park on top of the railway tunnel.
- A canal above the underground parking garage.
- (Re)construction of roads and streets.

(In the second construction phase the other two tracks were realised between Rijswijk and Delft-Zuid.)

The construction of the railway tunnel, the train station, and associated bicycle shed, the municipal office, public spaces and the parking garage were tendered as a composite contract by the clients. When the decision was made to build in 2005, the costs for the tunnel and the public space were estimated at 500 million euros. At the end of the year 2015 it was clear that the final costs would amount to more than 800 million euros. This difference had arisen due to delays during construction, the complexity of the project and the expansion of the project scope. The municipality of Delft had initially promised a contribution to the railway tunnel based on the expected profit from the development of the area. However, due to the international financial crisis, the real estate market collapsed during construction, causing profits to evaporate. The municipal office, other offices and housing were financed separately, and the housing was realised later than planned.

Significance

The complex nature of the railway in Delft has a long history. The first ground floor route and station date from 1847 as part of the Amsterdam – Rotterdam railway line. The subsequent bigger

Previous pages: view of old and new station, canal, bus platform and bicycle storage completed in 2015. [© Jannes Linders, JHML1503-0760]



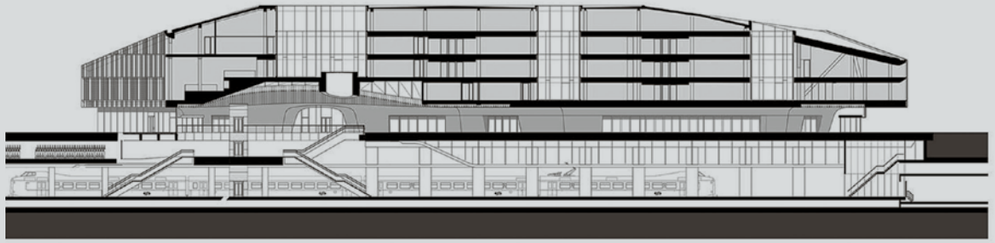
Amended urban plan from 2013 by Palmbout Urban Landscapes, in extension to the original plan by Joan Busquets from 2003. Legend: 1 Historic center. 2 Westerkwartier. 3 Voorhof/Poptahof-Noord. 4 Station square. 5 Station, Municipal office. 6 Van Leeuwenhoekpark. 7 Nieuwe Gracht. 8 Van Leeuwenhoekkwartier. 9 Coendersbuurt. 10 Abwoudtse Hof. / Bottom left: location of Delft and spoorzone along the railway connection Amsterdam – Rotterdam. [© Palmbout Urban Landscapes]

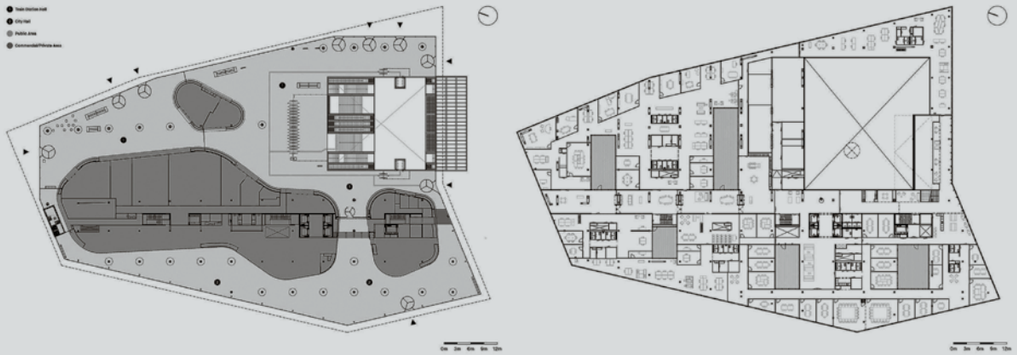
The then new railway viaduct built in 1965 near windmill De Roos, still with the original ground level tracks which were removed later. [PD Het Utrechts Archief, L. Hessels] **/ Now demolished townhouses at Van Leeuwenhoeksingel and the old station in 1956.** [PD Stadsarchief Delft, Jospé Arnhem] **/ View of the railway viaduct from Westvest in the direction of Bolwerk, Spoorsingel and Phoenixstraat in 1967.** [PD Stadsarchief Delft, Municipal police]











Cross-section of the floorplan of the ground level of the station's main concourse and of the first floor, showing the building of the municipal office. [© Mecanoo]

station, opened in 1885, was preserved in the new Spoorzone design and now has a monumental status. The new, larger station was opened in 2015. With the realisation of the railway tunnel and the restoration of the canal with several bridges, a connection was established between the historic city center, the urban expansions of the early 20th century, and the station area. In addition, a completely new mixed living and working neighbourhood was created around the station and park. With its high density, programmatic mix, limited parking options and low car ownership, the new district has good accessibility and a lively and high-quality living environment. The improvement of the latter has also been reflected in the additional 10% increase in economic value of the existing real estate within 500 metres, amounting to 400 million euros (Van Ruijven & Tijm, 2023). This is in addition to the value of the new constructions. The last homes and offices will be completed around 2030. Several parts of the Spoorzone have earned professional awards for innovative engineering and construction, architecture, and urban design and development.

Jan Nederveen, Gemeente Delft

LOCATION: Delft ■ **CLIENT:** Ministry of Infrastructure and Water Management & Municipality of Delft ■ **URBAN DESIGN AND DEVELOPMENT:** Joan Busquets, Palmbout Urban Landscapes ■ **ARCHITECTURE:** Mecanoo, Benthem Crouwel Architects ■ **ENGINEERING:** ProRail, Grontmij, Witteveen+Bos ■ **CONSTRUCTION:** Mobilis BV, CFE NV, Dura Vermeer Groep NV, Ballast Nedam Ontwikkeling, NS Vastgoed ■ **REALISATION PERIOD:** 2009-2015, 2018-2025.

FURTHER READING ■ Gemeente Delft. (2003) *Masterplan Spoorzone.* Masterplan op basis stedenbouwkundige visie Joan Busquets. Gemeente Delft ■ Gemeente Delft. (2005). *Delft, Spoorzone.* Bestemmingsplan. Gemeente Delft ■ Ministerie van Infrastructuur en Waterstaat. (2003). *Milieueffectrapportage (MER) Spoorzone Delft.* Ministerie van Infrastructuur en Waterstaat ■ Palmbout Urban Landscapes. (2012). *Delft Spoorzone, Zicht op Delft.* Palmbout Urban Landscapes ■ Van Ruijven, K., & Tijm, J. (2023). *Leefbaarheidseffecten van integrale infrastructuurprojecten: Inzichten uit onderzoek.* Centraal Planbureau (CPB).





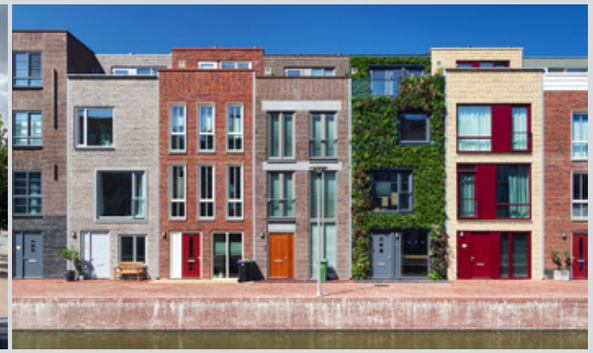


Demolition of railway viaduct. [CC Tukka] **/ Construction of the railway tunnel called William of Orange tunnel, referring to the historic bond of the royal family with Delft.** [CC Bennie91] **/ Reconstruction of the former city canal and construction of parking entrances on the roof of the underground parking located on the site of the demolished viaduct.** [CC Steven Lek]



The main concourse of the station connects, via a mezzanine level, the ground level, underground bicycle shed and platforms, and includes an entrance to the municipal office. The ceiling shows a historic map of the City of Delft. [© Mecanoo] **/ New houses at Bolwerk and Coendersbuurt.** [CC Sietske / CC Rob Oo]











Top: Port of Rotterdam: the coal-fired power plant Maasvlakte in operation at night. [CC Frans Berkelaar] **/ Satellite photo of the Port of Rotterdam.** [PD NASA Earth Observatory, Joshua Stevens] **/ Satellite photo of the Port of Antwerp** [CC European Space Agency (ESA)] **/ Port of Antwerp: transhipment of containers in the Deurganck dock.** [PD Alf van Beem]



FLEMISH–DUTCH DELTA

INTEGRATED LONG-TERM HARBOUR PERSPECTIVES

What future can the large and specialised ports in the Flemish-Dutch delta expect? Can they continue what they have always been doing? To what extent will goods flows change over time? When will the circular economy become predominant? When is the share of renewable energy substantially larger than that of fossil energy? Will the sea level rise continue to be linear and predictable, and will the ports remain easily accessible? These are all questions about developments that are surrounded by uncertainties, and all have a spatial dimension. Can a 'what-if' approach, in which a representation of a certain situation in the future is essential, help to gain insight into the future modus operandi of a port and the related measures that are needed to adjust to the various developments? How can short-term decisions also contribute to long-term adjustments?

Due to economic developments, climate change and sustainability goals, transitions are needed (Bierens et al., 2022). Therefore, currently, many transition strategies are being developed, for instance for future economies, energy transition, circularity, and climate adaptation. Transition strategies are developed at varying spatial and temporal scales, from a local to regional and (inter)national level and focusing on various time spans from short- to long-term. The interventions related to these transitions often require space or have a spatial impact. Usually, in the first development phase, these strategies are developed sectorally for a particular system like energy or water. These strategies have the tendency – based on the indicated transition path – to quantify the space required for a transition numerically. The quantified spatial claims in the strategies are typically not yet spatially projected, nor have relations been established with stakeholders to explore the spatial claims of other relevant transitions in the same region. This results in conflicting spatial claims in time and space and missed opportunities for alignment.

A new methodology has been developed to confront different sectoral transition strategies, identify conflicts, and make necessary decisions clear in an early stage. Designers, together with key experts who contribute in-depth sectoral system knowledge, explore the spatial impact of sectoral strategies in expert workshops. Different possible interventions will be clustered into a coherent sectoral strategy to limit the number of variables, which help decision makers to get grip on different potential future directions for an area. So-called 'basic attitudes' will be formulated, expressing priorities and goals from which choices for measures and interventions can be derived. Per attitude, a series of integrated long-term perspectives will be developed, which correspond with the different sectoral adaptation pathways that have been developed, so cohesive integrated long-term transition strategies can be defined. [Integrated Transition Strategy, page 90]

A study, conducted in the period 2023-2024, attempted to find answers regarding spatial claims within the Flemish-Dutch harbour complex based on the application of this new methodology (Nillesen et al., 2024). Sectoral spatial claims were spatially projected, based on a *research by design* approach with close involvement of port experts. The purpose of this study was to develop an integrated transition strategy, based on confronting alternative sectoral transition strategies in space and time, to explore potential spatial conflicts or opportunities early in the process. When reflecting on the different long-term strategies, opportunities and conflicts were revealed between different transitions in space and time. This offered new insights, which can inform priorities for short-term decision-making: can all long-term transition goals be achieved, and what decision-making is required to prevent conflicts or seize opportunities? [Research by Design Framework, page 108]

Study of the Dutch-Flemish harbour network

For this study, the cross-border Flemish-Dutch harbour network in the Netherlands and Belgium was used, as a case to apply the methodology to explore transition strategies for the harbour economy, energy transition and climate adaptation. This project was commissioned by the Board of Government Advisors (CRA) and the Flemish-Dutch Delta Network. The research by design was performed by Defacto Urbanism, CLUSTER landscape and the Erasmus Centre for Urban Port and Transport Economics, supported by and in cooperation with experts from the commissioner, who organised the workshops and invited experts and stakeholders to participate (Nillesen et al., 2024).

The case study focused on the Flemish-Dutch Delta Network, a partnership in which the provinces of Antwerp, North Brabant, East Flanders, West Flanders, Zeeland, and South Holland cooperate, with a focus on economic and logistical development. This delta – in the confluence of the Rhine, the Meuse, and the Scheldt – is an economic and logistical gateway between the North Sea and North-West Europe. Its Rotterdam-Antwerp harbour network includes the ports of Antwerp-Bruges, North Sea Port (Vlissingen, Terneuzen, Ghent), Moerdijk, Dordrecht, and Rotterdam.

First, the focus area and the relevant systems (harbour, energy, water) and transitions were selected (circular economy, energy transition, climate adaptation). Based on desk research and a first series of joint fact-finding expert workshops (Figure 1), for each transition, maps were made of the current system (describing its spatial characteristics and relevant underlying mechanisms), occurring and expected trends were described, and potential interventions were collected (Bierens et al., 2022). Four basic attitudes were formulated based on their outlook on priorities and goals, and considering relevant decision-making levels; for instance, are economic growth or sustainability goals the main drivers? Are national or local politics dominant in decision-making? In a workshop, narratives were derived from these attitudes for each transition, which includes a selection of measures in space and time. During a third integrating workshop, the narratives for each transition were combined into integrated, long-term perspectives that were described and mapped. In this, (spatial) conflicts or opportunities occurred. The way these were addressed differed per attitude since different attitudes resulted in different priorities. The results were discussed and presented to the stakeholders and local decision makers.



Figure 1. Participants in one of the research by design workshops, where the different systems – harbour, energy, and water – are mapped. [© Defacto Urbanism]

System mapping of the harbour network

The three transitions explored in relation to the harbour network are circular economy, energy transition and climate adaptation (Figure 2). The current harbour, its specialisations, and the freight-transport network of the area were inventoried and mapped, as well as the circular network, energy network, and water and soil conditions, along with their relevant drivers for change. The system mapping has led to several questions which were relevant on in the next phase of formulating the basic attitudes.

The harbour system and the transition to a circular economy – The ports of Rotterdam and Antwerp are transhipment points for containers and bulk, between the North Sea and the hinterlands of Germany and France, via inland shipping, rail, pipelines, and road networks (Bureau Voorlichting Binnenvaart, 2005; De Vries et al., 2021a; 2021b). In Rotterdam, crude oil is stored and processed into basic and petrochemical products. In Antwerp, crude oil (mainly supplied via Rotterdam's pipeline)

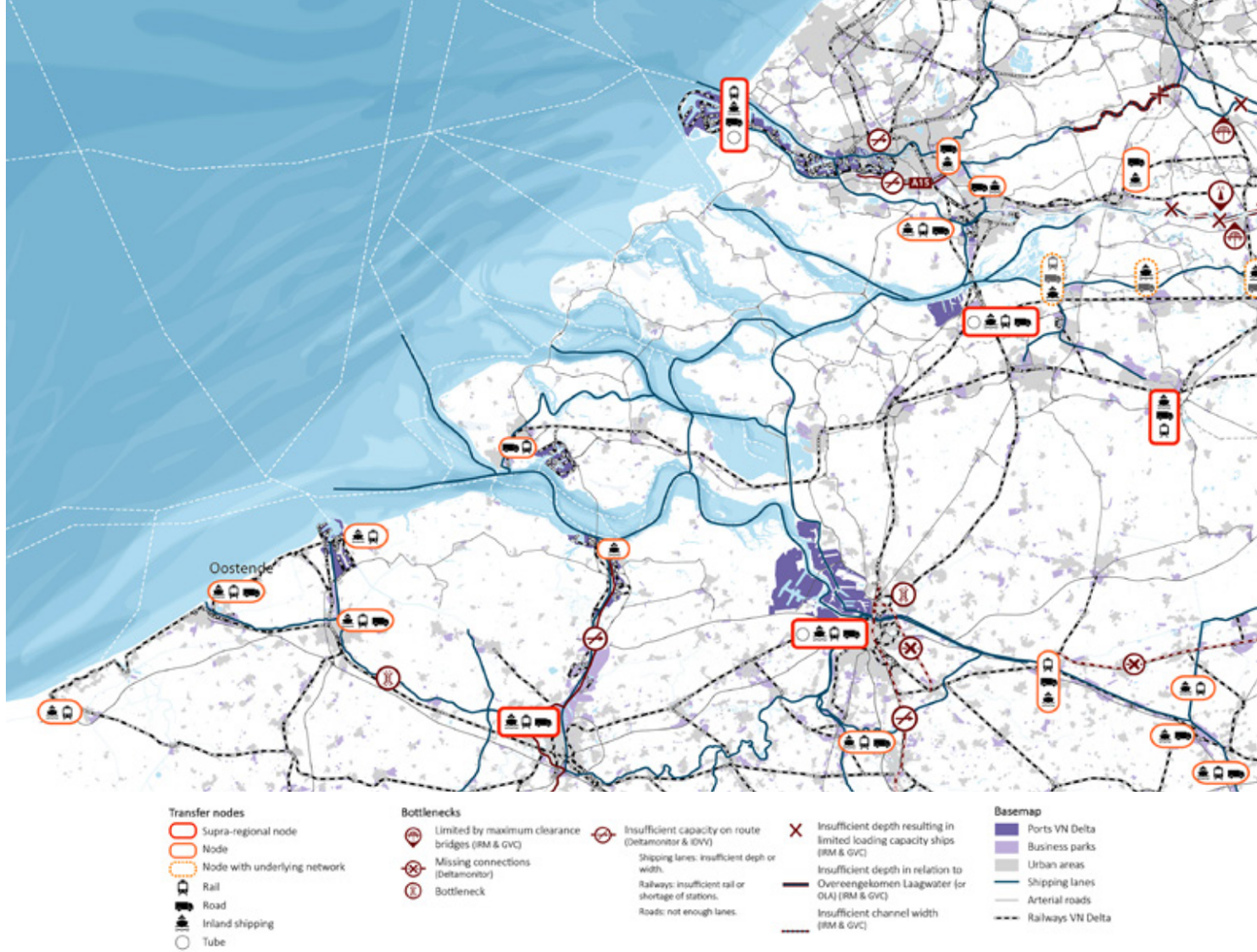


Figure 2. Overview map of the Flemish-Dutch Delta with the harbour network and its transport connections. [© Defacto Urbanism]

is processed into fine chemical products. The harbour of Zeebrugge complements Antwerp with container transhipment, specializing in cars. In addition, there are important manufacturing clusters in Oostende, Dordrecht-Zwijndrecht-Sliedrecht, and Rotterdam, specialised in shipbuilding and offshore. The ports of the North Sea Port are characterised by petroleum refining in Vlissingen and biochemistry in Ghent-Terneuzen (Figure 3). The primary challenge in transitioning to a circular economy is the need for a more sustainable use of materials to achieve the Dutch national goal of being entirely circular by 2050. Bulk flows of mainly raw agricultural and energy materials will decrease in time, while recycling and processing of waste and residual flows will require additional space. Relevant trends include the changing demographics, where we see that (dependent on immigration rates) the population is likely to shrink and age, leading to a shortage of labour (Te Riele et al., 2019). The digitalisation and automation of processes will require new skills for harbour workers. Also, the changing world economy has a major impact on the development of ports; raising import costs may challenge the current 'just in time' delivery-based container import model, and there is a wish to become less dependent on other continents. This results in more prominence for shorter-distance sea shipping with smaller vessels. This raises questions like to what extent the current role of ports will remain relevant, and what new role the ports will take on.

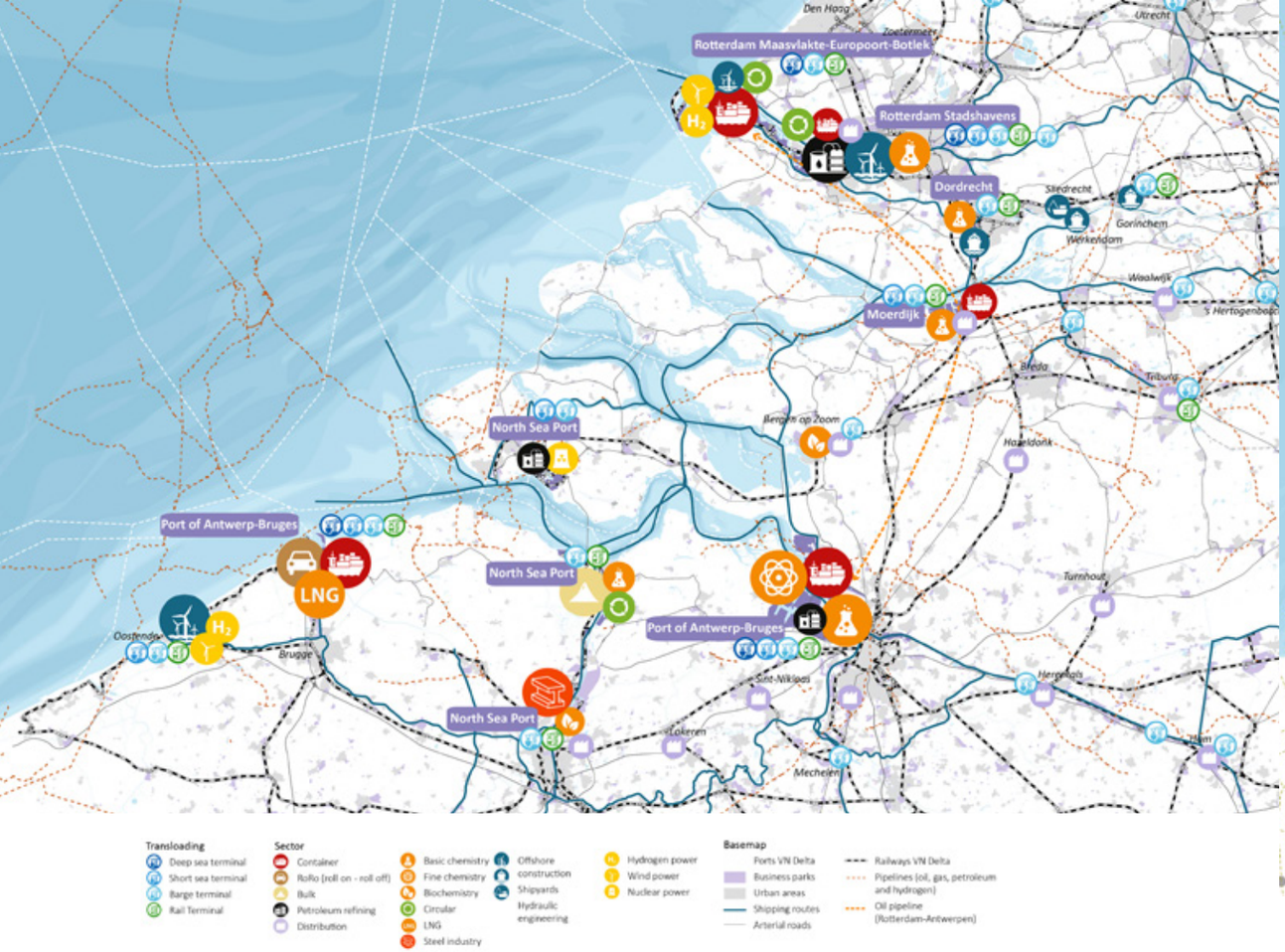


Figure 3. Specialisations of the harbour network. [© Defacto Urbanism]

The energy system and the transition to renewable energy – The ports are also important energy supply hubs, still mainly based on fossil fuels (Figure 4). Half of the goods transhipped in Rotterdam currently consist of crude oil, oil products, LNG, and coal. Crude oil is mainly imported from the Middle East and shipped to Rotterdam, natural gas is imported via pipelines from Germany and France to LNG terminals such as in the port of Zeebrugge, and nuclear energy is generated in the Borssele nuclear power plant. The energy system needs to transition to meet sustainability goals and is aiming to reduce fossil fuels, increase renewable energy, and promote energy efficiency. Renewable energy currently consists of on- and offshore wind farms, with landing points in Zeebrugge and Rotterdam. In addition, energy is generated to a limited extent at various locations from the sun, waste, biomass, and combined heat and power stations (CHP) for the purpose of electricity transport. The transition will require an extension of the renewable energy sources, such as wind, solar, hydrogen, biomass, waste, and nuclear energy production, and the use of residual heat. The new energy sources will require landing points, storage space, and new transportation networks. This will require a spatial reorganisation in the harbours, where spatial claims are now dominated by fossil energy sources. Industry is responsible for approximately 30% of the total current Dutch CO_2 emissions and is therefore an indispensable building block for a low-carbon society (CBS 2023). This raises questions like to what extent the Netherlands and Belgium want to become self-sufficient in the field of energy, and what role the ports will play in this.

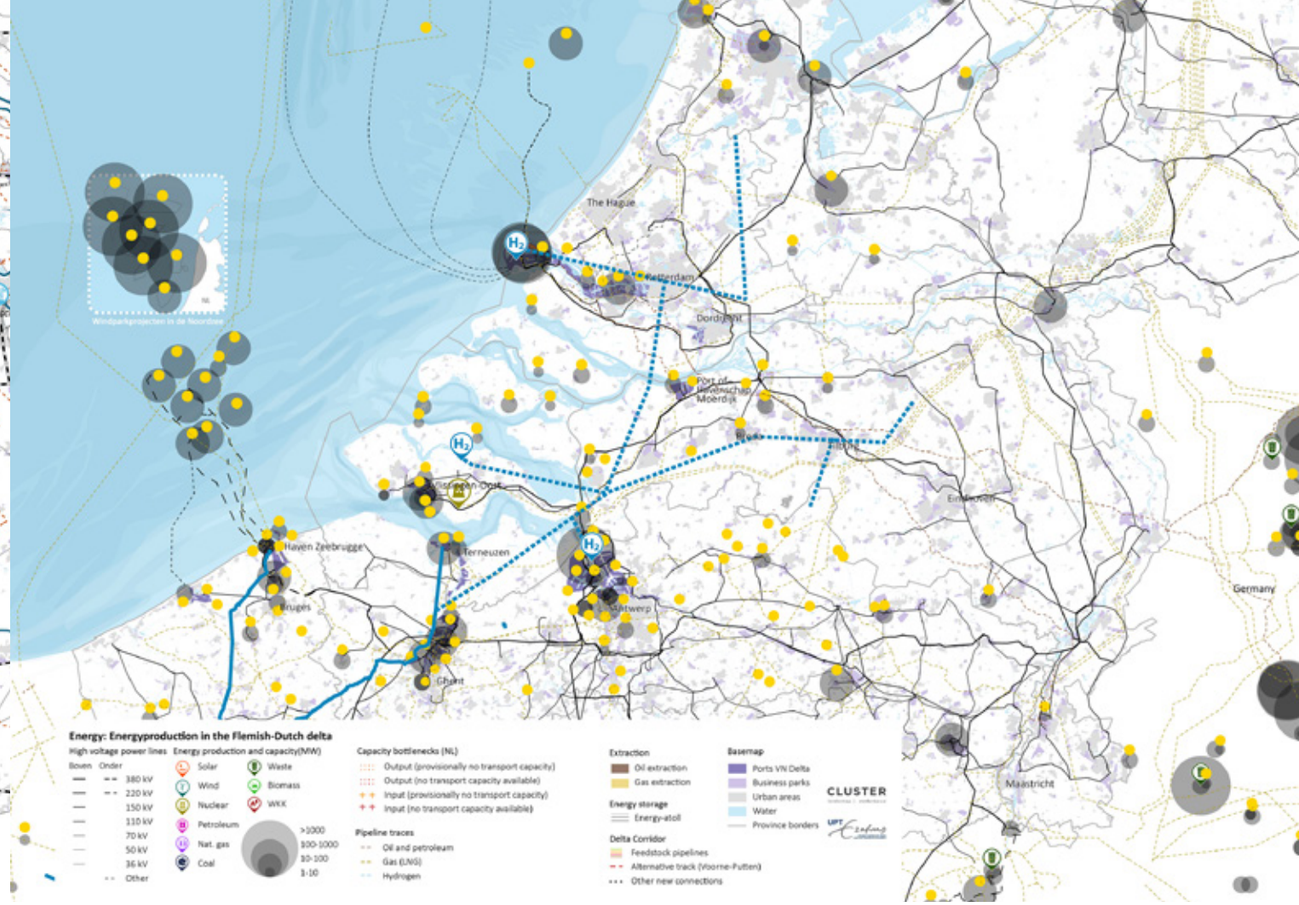


Figure 4. The energy system and its transition to renewable energy. [© Defacto Urbanism]

The water system and adaptation to climate change – Climate change is considered in this study in relation to the water system of the Flemish-Dutch Delta and the changing conditions that are expected to occur due to climate change. The delta only partly retained its open connection after the construction of the Delta Works from 1953 onwards (Figure 5). These open connections through the Nieuwe Waterweg (New Waterway) and the Western Scheldt are essential for shipping and ecology. In the closed-off estuaries, maintaining water quality became a severe challenge, as is the sediment balance (Programmabureau Zuidwestelijke Delta, 2011). Important transition challenges are the adaptation to sea level rise and more extreme rainfall events in this area, which is vulnerable to flooding and water damage. Water is, where possible, discharged naturally via rivers and canals and pumped out of the polder areas. The freshwater supply from rivers will decrease during prolonged dry periods, while the availability of fresh surface and groundwater is under pressure due to increasing salinisation and the growing demand for water from cities and industries. Explorations for extending the flood risk protection and water supply system result in system choices regarding closing of the estuaries or remaining an open delta, which will impact agriculture, harbour accessibility, and ecology, and no change cannot benefit all (Nillesen et al., 2021). This raises questions like to what extent the water system can continue to serve present and future land use, and which land use has priority in this. [Flood Defences, page 280]

Formulating basic attitudes and integrated transition strategies
In the next step, four basic attitudes for decision-making given on the required transitions were formulated:

1. *Classic Mainport*: focuses on prolonging current spatial-economic functions. This does have consequences, as burden shifting is accepted, as well as risks of shocks resulting from climate change and geopolitical developments.
2. *Recycle Delta*: also aims to maintain the current economic structure but strives for a more robust system in which operations, flows, and technologies become more sustainable. Significant investments are needed to make ports more sustainable and the system more robust. Sustainability may impact profit margins.
3. *Manufacturing Industry*: this achieves sustainability goals by a transition of land use and production processes and accepts the reduction of economic growth. This results in new spatial-economic structures focused on broad prosperity.
4. *Recycle Regions*: local decision-making, and initiatives steer transitions, and are strongly influenced by local interests and the public debate. This focus on the region and the short term means there is no (inter)national integrated and coordinated long-term strategy for addressing climate change. Without (inter-)national strategic choices, balancing of interests, and coordination, the (inter-)national sustainability goals are unlikely to be achieved.

In contrast, the first three attitudes can be seen as a series with increasing sustainability, which may require increasingly significant changes. The four basic attitudes have been elaborated per sector before being combined into integrated transition pathways and strategies (Figure 6). This step is important to discover the overlaps and confrontations of the different sectoral developments in time and space.

1. Classic Mainport – In this attitude and its transition strategy, the primary focus is on economic growth and international trade. The network maintains its current position and remains a dominant economic gateway (in terms of container and energy transport) to Europe. Existing land use and economic models are maintained and facilitated for as long as possible. Antwerp and Rotterdam retain their status as main ports and play a crucial role in the import and transit of hydrogen (imported from areas where it is easier to produce, such as the Middle East), making it a central hydrogen hub in North-Western Europe. Also, this alternative still focuses on the distribution of containers and the storage of container cargo for further distribution within Europe. Pressure on space is high, as the energy transition will require fossil and renewable sources to coexist. In addition, the transhipments and container handling scale up, resulting in the construction of the third Maasvlakte for Rotterdam, and Zeebrugge, which extends its transhipment function for Antwerp. The use and processing of fossil fuels will be maintained for as long as possible. Sustainability is approached from a 'green growth perspective' and eventually leads to the replacement of fossils by hydrogen and renewable fuels, making industry and transport in the region more sustainable. The focus on international trade creates a strong dependence on geopolitical changes and tensions. There is a strong belief in engineering solutions, which also permeates attitudes toward nature and the water system. Both the Western Scheldt and the Nieuwe Waterweg remain open connections to the North Sea, ensuring shipping and ecological connectivity. Technological solutions facilitate human land use for as long as possible. The water system will require technical extensions to be able to facilitate this open harbour system, resulting in dredging, desalination, and dike reinforcements, despite the effort needed to mitigate the

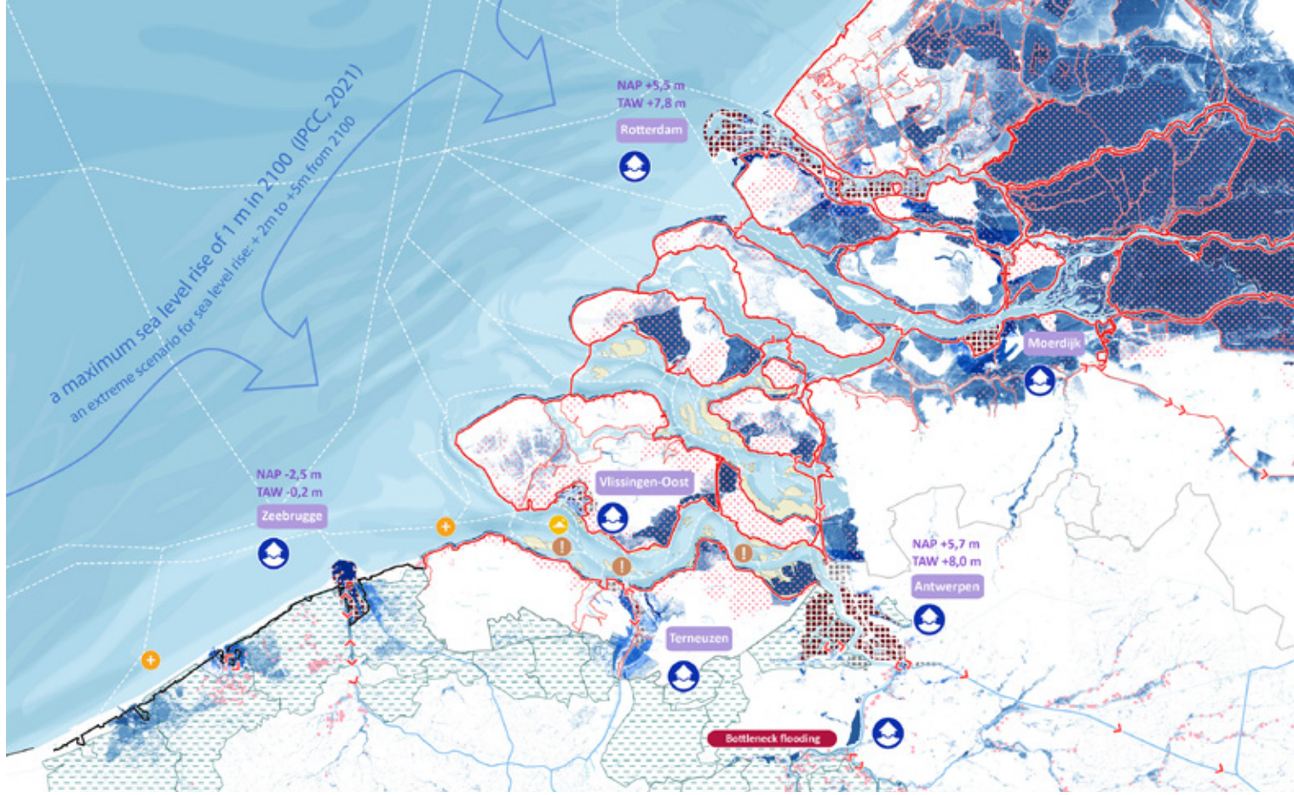


Figure 5. The water system of the delta and its challenges. [© Defacto Urbanism]

risk of shocks and damage from more extreme weather events. During droughts, the Rhine and Meuse hinterland waterways are temporarily impassable, and businesses will have to pause their production processes due to a shortage of processing and cooling water. Businesses accept the damage that results from this.

2. Recycle Delta – In this attitude and its transition strategy, economic growth remains important; however, European policy goals are being pursued, with a focus on broad prosperity. The ports remain main ports but will transform into material processing recycling hubs. Port activities are evolving, with a focus on transitioning from traditional bulk flows to circular flows, with a specific focus on the European market. Existing infrastructure will be reused; however, additional space is required for storage and production. The energy transition results in the import of biomass, green gas, and hydrogen, in addition to significant growth in solar and wind energy. Extensive application of CO_2 capture, reuse, and underground storage takes place via a central CO_2 network. The processing industry focuses on high-quality processing of recycled materials, biomass, cooking fats/oils, and semi-finished products (that still result in CO_2 emissions). The flow of goods is taking on a new dynamic with bidirectional movements (materials are brought

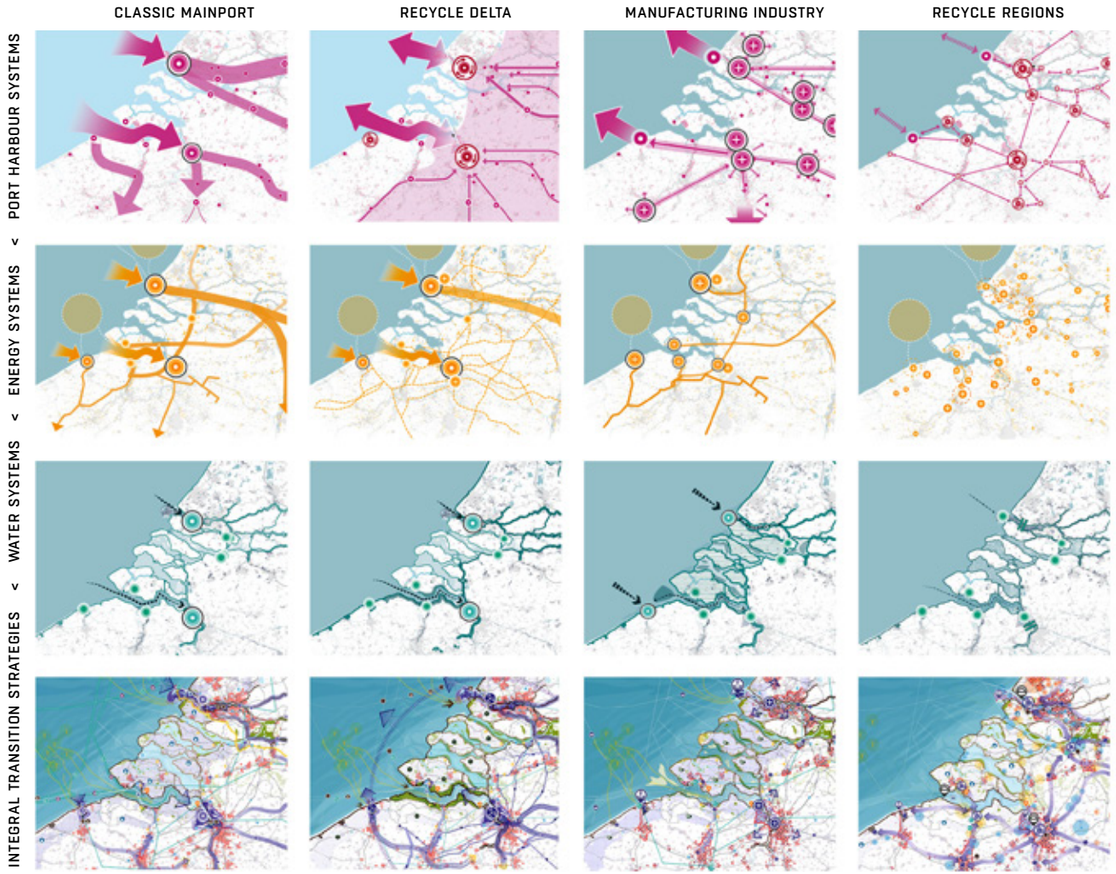


Figure 6. Overview of the different sectoral system transition strategies and finally the integrated transition strategy per basic attitude. [© Defacto Urbanism]

towards the harbours for transhipment), shorter distances, and smaller but more frequent flows. There is global important export of recycled goods; however, trade is primarily focused on Europe, and the ports will become a crucial hub in the circular network of North-Western Europe. The focus on circularity will lead to more logistics points for recycling within cities, and the pressure on space remains high. Space will become available due to the disappearance of functions, such as oil refining. The water system is made more robust with the introduction of intertidal zones that buffer flood water and tides and keep the Antwerp port accessible. The focus is on local water retention and smart use (subsurface storage, improved soil conditions, different water levels, saltwater cooling, and reuse of processed water) and adapting operational practices (salt-tolerant crops, aquaculture). The open delta system remains for shipping; as a result, the delta will become more salinized, which benefits ecology, but impacts agriculture (which needs to adapt).

3. Manufacturing Industry – In this attitude and its transition strategy, there is a growing awareness that the economy must transform to become more sustainable. Major investments are being made in knowledge, technology, and high-quality manufacturing. The process industry and refining are phased out, freeing up space for high-quality, knowledge-intensive manufacturing with a global market. The port transforms from a transit to a production port that adds value, and

significant investments are made in knowledge development and innovation. Industry focuses on offshore wind, offshore solar, and other innovative applications such as floating islands, with a strong emphasis on digitalisation and automation. The ports are fully committed to hydrogen production; solar, wind, and nuclear energy are being used both onshore and offshore – which requires significant space and is only feasible through technological advancements. Large-scale port activities are relocated to Maasvlakte or Zeebrugge as offshore energy landing points. Relationships between regionally collaborating hubs are strengthened, and there is a global export market for knowledge and products. Former urban port areas are transforming into diverse residential and work areas, where the integration of manufacturing plays a crucial role in collaboration with knowledge and education. The natural water system is restored where possible, resulting in an open ecological system with less dredging and deepening of the Scheldt. Sand banks in the channel will limit salt intrusion and protect against storms surge from the sea. Flood retaining landscapes focusing on multi-layered safety through a combination of strengthening and widening barriers and mitigating impacts In the open delta, land use will be adjusted if it is no longer compatible with the climate; due to salinisation, some agricultural areas will transform into nature or recreational functions, which supports the local economy.

4. Recycle Regions – This attitude and its transition strategy opt for a more self-sufficient course, with limited international trade. There is strong societal sentiment against globalisation and in favour of strategic autonomy. The delta is closed off to provide fresh water for agriculture and local industries. This impacts ecology and the harbours; the importance of the main ports decreases. The discussion on the closing of the Western Scheldt may cause controversy between Belgium and the Netherlands. Port activities primarily focus on a decentralised network of hubs, with a strong emphasis on recycling, repair, and circular small-scale manufacturing. This creates small, frequent, short-term freight flows. Local and small-scale economies are preferred over large international companies. Harbours are being used by businesses for local storage and circular activities, while larger industries causing nuisance are being phased out. The region also strives for energy self-sufficiency with a decentralised network and local production close to consumption. For energy transition, the area relies on production through wind, solar, and geothermal power. Many small-scale manufacturing, recycling, and repair facilities are integrated into the city. By allowing local initiatives, unplanned sprawl and urbanisation are likely to occur. The water system supports agriculture and focuses on fresh-water availability, and the water storage capacity of the estuaries is being increased. In addition, more water is collected and stored locally. Scattered local initiatives focus on ecology, though the main emphasis is on urban and recreational green spaces.

How to consider the integrated transition strategies and short-term decisions while developments continue?

The study shows that various directions can be combined to a certain extent. The availability of space limits what can happen simultaneously; in time, there will be overlapping of spatial claims during a transition that need to be addressed (for instance, regarding space required in harbours for the current non-renewable energy, space for storing recycling materials, and energy production). A short-term strategic decision is needed on how to deploy the scarce space and whether to extend the harbours or actively pursue the accelerated phasing out of current fossil fuel-consuming areas.

A decision concerning sea level rise and the delta – to remain open or transition towards a closed delta –will strongly impact the harbour, ecology, and freshwater availability for agriculture and industrial usage. The long-term perspective for the delta's water system requires a joint international vision. The ambition to keep the delta – the Nieuwe Waterweg and the Western

Scheldt – open is a key principle for ecology and the port. Due to climate change, this open delta will require adjustments in business operations, design, and land use (of ports, ecology, and agriculture).

Long-term strategies for circularity and the energy transition will have a significant impact on the development prospects of the Flemish-Dutch Delta. In the short term, different sustainability and energy initiatives can coexist. However, strategic choices and vision development are currently lacking, but will be necessary to support decision-making regarding the allocation of scarce space and investments in networks. A clear strategy is required to enable provinces, municipalities, and businesses to align with national policies and to prevent regrettable investments.

To achieve the national and European objectives for energy and circularity, and to prevent shifting costs and burden to future generations, (inter)national strategies for new spatial economic structures are essential. Even with adjustments, the current spatial economic structures will eventually fail. The progressive approach behind the Manufacturing Industry transition strategy is essential for achieving long-term objectives. This will require making difficult choices, such as transforming agriculture, investments in more sustainable and future-proof systems, and accepting a decline in economic growth to achieve broad societal prosperity.

Reaching the long-term ambitions – adapting to circularity, energy transition and climate change – will not be possible without (international) coordination that secures early decision-making on priorities and investments that support the long-term ambitions.

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REFERENCES ■ **Bierens, E., Declerck, J., & Wouters, J. (2022).** ***Ruimtelijke opgaven voor de havens in de Vlaams-Nederlandse Delta.*** **College van Rijksadviseurs (CRA), Team Vlaams Bouwmeester** ■ **Bureau Voorlichting Binnenvaart. (2005).** ***Waardevol Transport - De maatschappelijke betekenis van het goederenvervoer en de binnenvaart.*** **Bureau Voorlichting Binnenvaart** ■ **CBS. (2024).** ***Uitstoot broeikasgassen 6 procent lager in 2023.*** **CBS. Retrieved from: https://www.cbs.nl/nl-nl/nieuws/2024/11/uitstoot-broeikasgassen-6-procent-lager-in-2023** ■ **De Vries, L., Nillesen, A.L., Zum Felde, M., Elings, C., De Leeuw van Wenen, R., Van de Geest, W., Verwij, K., Verhees, F., & Van der Veen, E. (2021a).** ***Toekomstagenda Corridorontwikkeling 2030, Perspectief voor samen werken aan en investeren in krachtige en duurzame oost en zuidoost topcorridors.*** **Topcorridors oost en zuidoost** ■ **De Vries, L., Nillesen, A.L., Zum Felde, M., Elings, C., De Leeuw van Wenen, R., Van de Geest, W., Verwij, K., Verhees, F., & Van der Veen, E. (2021b).** ***Toekomstagenda Corridorontwikkeling 2030. Analyse Toekomstagenda Corridorontwikkeling. Achtergrond-document Analyse Beschrijving van de Oost en Zuidoost topcorridors.*** **Topcorridors oost en zuidoost** ■ **Nillesen A.L., Zum Felde, M., Van Alphen, J., Kielen, N., Hekman, A., Booister, N., Diermanse, F., Haasnoot, M., & Niesten, M. (2021).** ***Versnelde zeespiegelstijging Zuidwestelijke Delta, Verslag gebiedssessie Kennisprogramma Zeespiegelstijging Zuidwestelijke Delta (20 mei 2021).*** **Kennisprogramma zeespiegelstijging** ■ **Nillesen, A.L., Swinkels, S., Kuipers, B., Verhoestraete, D., & Emmeri, M. (2024).** ***Toekomstbestendige havens in de Vlaams-Nederlandse Delta. Ruimtelijke langetermijnverkenning.*** **College van Rijksadviseurs (CRA)** ■ **Programmabureau Zuidwestelijke Delta. (2011).** ***Lange termijn verkenning Zuidwestelijke Delta, probleemanalyse fase 1.*** **Deltaprogramma, deelprogramma Zuidwestelijke Delta** ■ **Te Riele, S., Huisman, C., Stoeldraijer, L., De Jong, A., Van Duin, C., & Husby, T., (2019).** ***Regionale bevolkings- en huishoudensprognose 2019–2050.*** **Planbureau voor de Leefomgeving.**

LESSONS

INTEGRATED LONG-TERM HARBOUR PERSPECTIVES

The setup, execution, and results of the study bring the following lessons:

- **Research by design can reveal spatial relationships and contradictions and inform policymaking.** The research by design approach is deemed valuable in spatially projecting spatial claims about different transitions and revealing the spatial dependencies and conflicts. This supports the debate and agenda setting for the required (international) strategies and short-term decision-making.

- **Commitment by policymakers is conditional on the involvement of experts and information gathering.** The use of expert workshops (though time-consuming) has proven to be valuable to speed up knowledge transfer regarding the transitions. The high-level commissioner was essential in being able to invite the right high-level experts to the table. The interpretations of the designers in transferring this knowledge to system maps and integrated strategic narratives were time-consuming and required the opportunity for experts to review, since some sector-specific nuances were easily misinterpreted.

- **Envisioning a particular future operation in a coherent way creates its own logic.** The basic attitudes were valuable in demonstrating that transition strategies are not merely a collection of measures. It became apparent that the attitude behind the selection of measures will have a major influence on the goals being achieved and the means available to do so.

- **The study offers prospects for policy development, which policymakers and other stakeholders must continue.** A discussion arose about whether the different directions should be combined into a preferred strategy; however, this would exceed the goals of the study, which focused on revealing the contradicting spatial claims and addressing strategic choices for political decision-making. Of course, further integrated strategy development would be essential to be able to develop strategies that can meet the sustainability and prosperity goals, as the current transitions will not be sufficient to do so. When working on an integrated strategy, of course, the focus will have to be even wider and transgress the current port-related scope.


WAGENBORG
BOTHNIABORG
DELFZIJL

FEATERED DESIGN: NIEUWE SLUIS TERNEUZEN

SECURING THE COMPETITIVE ECONOMIC POSITION OF GHENT AND TERNEUZEN

The construction of a new ship lock within an existing lock complex is a major undertaking that encompasses much more than simply fitting it into the structure itself. Apart from enabling shipping in the canal behind it, existing surrounding systems, such as the flood defence and the ecology, must not be adversely affected. How were these challenges considered in the project for a new lock in Terneuzen?

CHARACTERISTICS

The locks of Terneuzen enable shipping in the canal that connects the seaports of Ghent in Belgium and Terneuzen in the Netherlands with the North Sea via the Western Scheldt. It ensures a constant water level in the canal, avoiding tidal water level differences of up to 4.5 metres to enter the canal. At the beginning of the 21st century, the complex consisted of three ship locks. In a design & construct project, a bigger lock was built to enable more and larger vessels to reach the port of Ghent and further.

Apart from the lock itself, the project comprises two bascule bridges, several quay walls, guidance structures, waiting and berthing places, a new service harbour, the demolition of the existing middle lock, deepening of the front harbours, and changing the road infrastructure.

The new lock has a length of 427 metres, a width of 55 metres and a depth of 16.44 metres. With these dimensions, it can accommodate sea-going Neopanamax vessels. The lock chamber is closed by two sets of roller gates with a length of 62 metres, a height of 26 metres and a weight of 2,000 tonnes each. Both the steel gates and the bridges were constructed in China.

Apart from its main function of enabling shipping, the lock complex assures that existing systems and functions in its surroundings are not affected:

- The lock complex is part of a flood defence system, protecting the hinterland against extreme sea water levels that on average occur once per 4,000 years. Taking a sea level rise of 0.60 metres into account, this has led to a top of the gate level of NAP + 9.5 m.
- The new lock discharges surplus water from the Flemish hinterland via the canal into the Western Scheldt.
- Roads and bridges are included in the lock complex so as not to disrupt the road traffic along the estuarine coast. All the locks, including the new lock, have two bridges to ensure that cars, cyclists, and pedestrians can always cross the lock.
- Sills were constructed as part of the floors of the lock heads to prevent sea water to flow into the canal and in this way negatively influence the water quality in the canal. The new lock will eventually operate energy-neutrally.
- The lock gates and bridges are coloured mint-green to blend in with the colours of the water and surrounding nature. This also aligns with the colours of the other locks. To further improve the spatial quality, the lock complex contains eight new recreational areas and a war memorial to commemorate five members of Rijkswaterstaat who were executed during the Second World War.

Previous pages: the Nieuwe Sluis in operation during a sea trial in 2025. [© project Nieuwe Sluis Terneuzen]



Topographical map of the municipality of Terneuzen situated on the Western Scheldt and connected to the Ghent-Terneuzen Canal, via the ship locks between the industrial area (west) and the city (east). The canal and two locks were built in the period 1823–1827. [CC Jan Willem van Aalst] **/ The middle lock of the complex, which dates to 1910, has now been replaced by the new lock. In 1968, the western lock for seagoing vessels and the eastern lock for inland vessels were opened. The construction is shown below.** [© Rijkswaterstaat]





Significance

The Ghent-Terneuzen Canal is part of the inland shipping route Rotterdam – Paris. With about 60,000 vessel passages per year (2021), it is one of the busiest lock complexes in the world. The number of vessel passages is expected to grow to 95,000 per year in 2040 after the completion of the Seine-Nord canal. The new lock is expected to secure the competitive economic position of Ghent (with a focus on bioenergy) and Terneuzen (mainly bulk, basic chemicals, circular industry) in the global economy.

To take stakeholders' interests into account, efforts were made to minimize the impact on the surrounding built environment. The construction method ensured maintaining the groundwater level in the area, preventing subsidence of houses and buildings. Vibrations and noise pollution were minimized as much as possible. To preserve the ecology as much as possible, construction work was avoided during the breeding season and future maintenance will also take place outside that season. Early stakeholder involvement resulted in no objections against ecological aspects of the design.

The project demonstrates that an integrated approach can be successfully applied, by acknowledging the significance of the surroundings, represented by stakeholders, and making them part of the project. In this way, multiple spatial scales were considered and intertwined. Culturally, the locks are part of the local community, just like the Second World War memorial.

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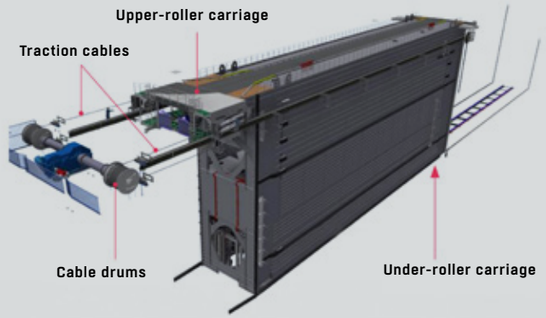
LOCATION: Terneuzen, Zeeland ■ **CLIENT:** Vlaams-Nederlandse Scheldecommissie (VNSC), a collaboration between Dutch and Flemish governments ■ **DESIGN AND CONSTRUCTION:** Contractor consortium Sassevaart, consisting of BAM Infra, Stadsbader Contractors, DEME (DEME Infra Marine Contractors B.V. and Dredging International N.V.), Van Laere N.V. and Equans ■ **REALISATION PERIOD:** 2017-2025.

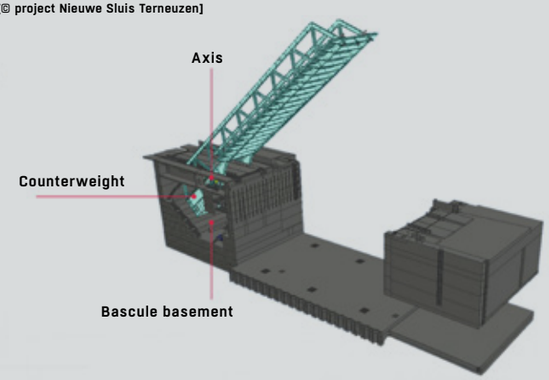
FURTHER READING ■ Van Doorn et al. (2021-2023). De Nieuwe Sluis Terneuzen. Five articles in *Cement* 2021-2, 2022-7, 2023-4, 2023-5, 2023-6 ■ Vlaams-Nederlandse Scheldecommissie (2015). *Hoofdrapport MER Nieuwe Sluis Terneuzen.* (VNZT-R-145-9).

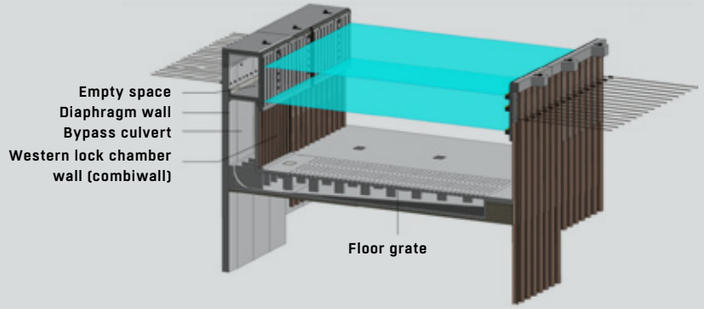




Aereal view of the Terneuzen lock complex with the old situation indicated in the background. / The 25-metre deep building pit for the inner lock head and the lock chamber of the Nieuwe Sluis. [© project Nieuwe Sluis Terneuzen]







The roller gates and the bascule bridges. [© project Nieuwe Sluis Terneuzen]

Culverts lead excess water from the Flemish hinterland via the inland lock head through openings in the floor of the lock chamber, from where it flows to the Western Scheldt when the sea gate is open. These culverts are used for the levelling of the water in the lock chamber as well. [© BAM]

Below: entrance to the western lock (left) and the Nieuwe Sluis (middle), seen from the Ghent-Terneuzen Canal, looking northeast. [CC Krib]





Blankenburgverbinding (A24): the Holland tunnel under the Zuidbuurt area, the viaduct of the Hoekse Lijn, and the sunken road along Krabbeplas towards the A20 on the north bank of the Nieuwe Waterweg (top). Connection of the A15 with the A24 and the Maasdelta tunnel between Rozenburg and the port on the south bank (bottom). [© Rijkswaterstaat, Topview Luchtfotografie]



BLANKENBURGVERBINDING (A24 MOTORWAY)

PARTICIPATIVE DESIGN FOR SPATIAL QUALITY AND ADDED VALUE

Infrastructure projects span many years in development, and their impact persist for decades, often affecting multiple generations. The space they occupy and the landscapes they traverse significantly influence land use and user experience for a wide range of stakeholders. While drawing a road from point A to point B may appear straightforward on a map, it involves many complicated issues, values, and concerns. How can we better understand the long-term consequences of route selection for a new road? How can we involve the insights and energy of diverse stakeholders? Can participative design in the early stages of a project, acknowledging the multifaceted meaning of the project across society and environment – as seen through design lenses – enhance its overall value and foster broader public commitment?

Infrastructure is most recognisable through its outward appearance: asphalt, concrete, steel, water, etc. However, this is merely a manifestation of an underlying dynamic system embedded in complex social, ecological, and spatial environments. As societies face rapidly evolving challenges – like climate change, urbanisation, population shifts, and digital transformation – the role of infrastructure must be rethought not just as technical support to enable social and economic functions, but as an active agent in shaping futures. Infrastructure is both a backbone and a reflection of social priorities, and its design carries the weight of long-term consequence.

Integrated infrastructure design has emerged as a necessary response to this complexity. It seeks to dissolve the silos of conventional engineering and planning practices, replacing them with interdisciplinary, multi-scalar approaches (Llancce et al., 2025). Rather than addressing single problems with isolated solutions, integrated design connects systems and its management – such as transport and water – while embedding broader ambitions like sustainability, spatial quality, and equitable access for diverse users. The question is no longer just how infrastructure functions, but what it enables, how it performs across time and space, and for whom it delivers value.
This shift requires a broader design lens – one that brings together technical, ecological, social, economic, and aesthetic considerations. Infrastructure must be understood not only in terms of its physical outputs but also through the processes by which it is conceived, debated, and developed. Design, in this view, becomes both a method of inquiry and a mode of collaboration. It facilitates dialogue between disciplines, fosters engagement with communities, and offers the imaginative capacity to envision future conditions. The act of designing infrastructure is thus inherently political, value-driven, and iterative. [Integrated Infrastructure Design Method, page 290]

Multi-level and multi-lens approaches are especially crucial in large-scale projects, as these interventions are not merely technical operations; they are social events. As Frick (2008) notes, mega-projects often generate friction – like controversy, complexity, and control struggles – as they reshape landscapes and livelihoods. The surrounding ‘project community’ can act both as resistor as well, as co-creator as they may experience the negative impacts of disruption, yet they also hold democratic influence as users, taxpayers, and voters (Ninan et al., 2022). This community is not a passive recipient but a field of diverse actors with situated knowledge, histories, and stakes. Recognising infrastructure as a shared space – materially and symbolically – requires a mindset that is adaptive and responsive. The long lifecycle of infrastructure means today’s design decisions have consequences for generations. Hence, integrating resilience and long-term thinking becomes essential. The water, transport, and spatial systems, for instance, are no longer separable concerns; they must be addressed together, as interdependent layers in a living landscape – often through

interventions such as multi-functional infrastructures (Ninan et al., 2024). Infrastructure in this context has both opportunity as well as responsibility – to support movement and flow, but also to safeguard ecosystems, strengthen social cohesion, and reflect the values of its time.

Within this broader framing, this contribution considers a multi-lens perspective on infrastructure design, using a concrete project to illustrate these ideas. The Blankenburgverbinding (A 24 motorway), a major infrastructure intervention in the Rotterdam region, serves as a fertile case for examining how integrated, interdisciplinary approaches are being applied in practice. By exploring the project through a series of 'design lenses' we aim to unpack the multiple meanings of integration and show how infrastructure can be regarded not just as a material manifestation, but as a process of collective intelligence that forms a dynamic system.

A multi-lens approach to infrastructure design

The reimagining of infrastructure as an integrated system calls for a theoretical framework that can address its multifaceted meaning across society, the natural environment, and the built world. Rather than viewing infrastructure solely as a technical or functional object, this perspective emphasises its embeddedness within broader spatial, ecological, and social systems. An integrated design approach provides a conceptual foundation for working within this complexity, encouraging a design practice that aligns infrastructural development with long-term social and environmental goals.

Central to this approach is a recognition of the interdependencies between technical systems and the contexts in which they operate. This is reflected in a series of design lenses that guide analysis and decision-making throughout the process. They focus on *functionality* – understanding how infrastructure enables movement and connectivity through engineering and transport systems. Closely tied to this is the notion of *performance,* which considers the reliability, availability, maintainability, and safety of these systems over time. A multi-scalar perspective is also essential, as infrastructure has multiple *intervention scales,* with different implications at local, regional, and national levels. Similarly, the capacity of infrastructure to adapt to changing conditions in time – such as shifting climate patterns and extreme weather events – demands a focus on *adaptivity* and *resilience. Sustainability* further expands this temporal dimension by foregrounding the impact of material use, energy consumption, emissions, and ecological consequences over the long term. Beyond technical criteria, *spatial quality* addresses how infrastructure is experienced by users, its value of use and future value, and how it shapes the character of place. *Perception,* in turn, examines the mental experiential quality of a road and the landscape – as perceived by road users, neighbouring communities, and those moving through the area. Infrastructure can also create *added value*: by contributing to economy, ecological restoration, recreation, social inclusion, and cultural-historic values. These broader contributions are often realised through *collaboration* – not only through stakeholder engagement as a key design input – but also through interdisciplinary and intersectoral cooperation that brings together diverse forms of knowledge, expertise, and institutional responsibility. It also embodies how different stakeholders interpret and relate to the project based on their needs, values, interests, and expectations. Finally, navigating the inherent *complexity* which infrastructure embodies – technically, institutionally, culturally, and socially – requires an approach that is iterative, integrative, and open to negotiation. Together, these ten lenses offer a structured yet flexible way to approach infrastructure not only as a system to be built but as a platform for shaping sustainable and inclusive futures. [Integrated Infrastructure Design Lenses, page 182]

Connecting region and economy and catering for existing qualities

The Blankenburgverbinding part of the initial Nieuwe Westelijke Oeververbinding project (NWO) – offers a compelling case study in integrated infrastructure design. Commissioned by Rijkswaterstaat, as the implementing organization of the then Ministry of Infrastructure and the



Figure 1. The Oranjeverbinding (left) and the Blankenburgverbinding (right) from Masterplan Rotterdam Vooruit as the predefined locations of the Nieuwe Westelijke Oeververbinding project (NWO) for the participatory process (Ministerie van Infrastructuur en Milieu, 2013). **/ Figure 2. Selected variants for the Oranjeverbinding and Blankenburgverbinding from the participative process.** [© BGSV bureau voor stedebouw en landschap]

Environment (Ministerie van Infrastructuur en Milieu), this project sought to connect the A15 and A20 motorways to alleviate congestion and enhance accessibility in the Rotterdam region. This includes the Port of Rotterdam and the Westland greenhouse horticultural area, located on opposite banks of the Nieuwe Waterweg, a canal which connects Rotterdam and the port to the North Sea. However, beyond its functional objectives, the project evolved to integrate environmental, social, and technical dimensions in a complex infrastructure initiative.

At the end of 2008, the ministry decided to start a so-called MIRT study[1] called Rotterdam Vooruit, an exploration for solutions to improve the accessibility of the Port of Rotterdam and the larger region of Rotterdam. Congestion issues, with a road network at the limit of its capacity and the foreseen growth, would hamper economic growth and increase the environmental burden. As a first outcome the Masterplan Rotterdam Vooruit (2009) addressed the need for an extra riverbank connection as an extension of the road network in the west of the region. The NWO project suggested two potential locations: the Oranjeverbinding and the Blankenburgverbinding (Figures 1–2). This project was strongly supported by regional administrative bodies.

The initial motivation behind the NWO project was clear: to improve accessibility and traffic flow for the port and region, while also relieving the pressure on the existing A4 Benelux corridor – one of busiest logistics corridors of the Netherlands – and making the network more robust in case of calamities. Also, the choice for a tunnel was evident given the location and the need for unobstructed navigation for the port. Right from the start it was clear that the new connection also had to fit in with the existing environment with the least possible environmental pressure like noise and visual disruption. Rather than being defined strictly as a transport issue, it was reframed as a spatial challenge, embedding the new connection better within the larger landscape and urban system. This redefinition – coined by Rijkswaterstaat as *area-oriented working on spatial quality* – marked a fundamental shift in approach: from solving only transport issues to

also prioritising spatial quality as a key value and driver in the design process (Ministerie van Infrastructuur en Milieu, 2011).

Participatory process with stakeholders from the area – Rijkswaterstaat adopted an *outside-in* participative planning and design approach, engaging early with local communities, businesses, and municipalities – not only to incorporate valuable area-specific knowledge, but also to build commitment and to facilitate a smoother and time-efficient procedural progress (Ministerie van Infrastructuur en Milieu, 2012). This was a departure from a traditional 'decide-deliver-discuss' top-down approach, now embracing a bottom-up model of 'discuss-decide-deliver'. For the so-called area scan the community was not just consulted; it was asked to contribute directly to the inventory of area knowledge and ultimately the design. Around 150 people responded to an open call, including residents, cyclists, businesses, and local authorities – organised in distinctive groups and alternative connections. Both the Oranjeverbinding (near Hoek van Holland and the Maeslant flood barrier) as well as the Blankenburgverbinding (between Maassluis and Vlaardingen, and Rozenburg at the south bank) were pre-defined as exploration areas in the Masterplan Rotterdam Vooruit. The participants' insights and knowledge about those areas formed the basis for the design sessions in four rounds in the first half of 2011 where values, qualities, challenges, ideas, priorities, and variants were literally mapped in a collaborative manner – addressing multiple dimensions related to the larger area and the locations (Figure 3). The sessions were guided by external moderators and supported by mobility and road design experts from Rijkswaterstaat. [Stakeholder Analysis, page 112] [Motorway and Railway Line Tracing, page 186]



Figure 3. A session as part of the participative process, discussing alternatives and variants. [© Busé Communications]

The sessions delivered a total of 63 solutions for a connection of which thirteen were qualified as variants. After the participatory process two variants for the Oranjeverbinding and three for the Blankenburgverbinding were selected as input for further investigation by the ministry. Another outcome of the area scan was a vision on the connection: (a) preserving and enhancing contrasting landscapes; (b) the relationships between the areas will take place with (transverse) structures, which ensure continuity; and (c) for the road user, the aim is to achieve unity in the road appearance for the route as a whole. This guideline for further design led to the following key requirements: (a) maintaining and enhancing the characteristics of the environment, (b) minimizing the effect on the environment, and (c) functional maintenance and strengthening of structures and networks. Both the vision and the key requirements were ultimately translated into the integration concept: the *concealed connection*. This was especially relevant for the area on the north bank due to its urban and natural character while the south bank is the location of the port and industry.

With area-oriented working on spatial quality as a guiding principle the aim was not just to move vehicles efficiently but also to harmonise the road with the surrounding environment like residential areas and the landscape. The stakeholder dialogues surfaced the area's historical and

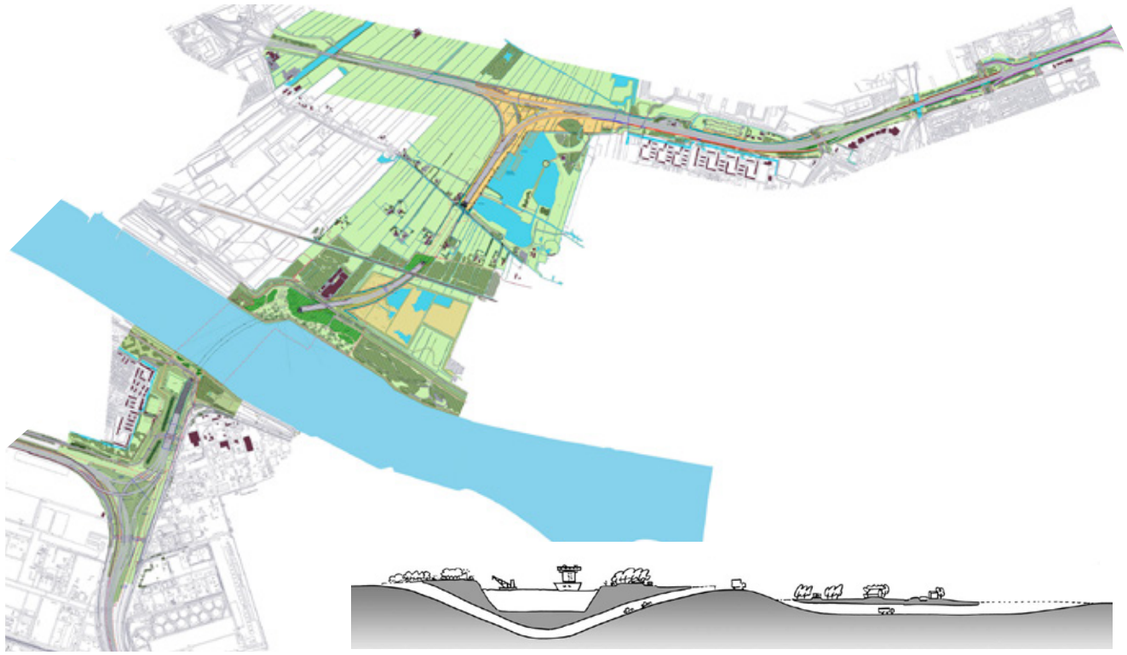
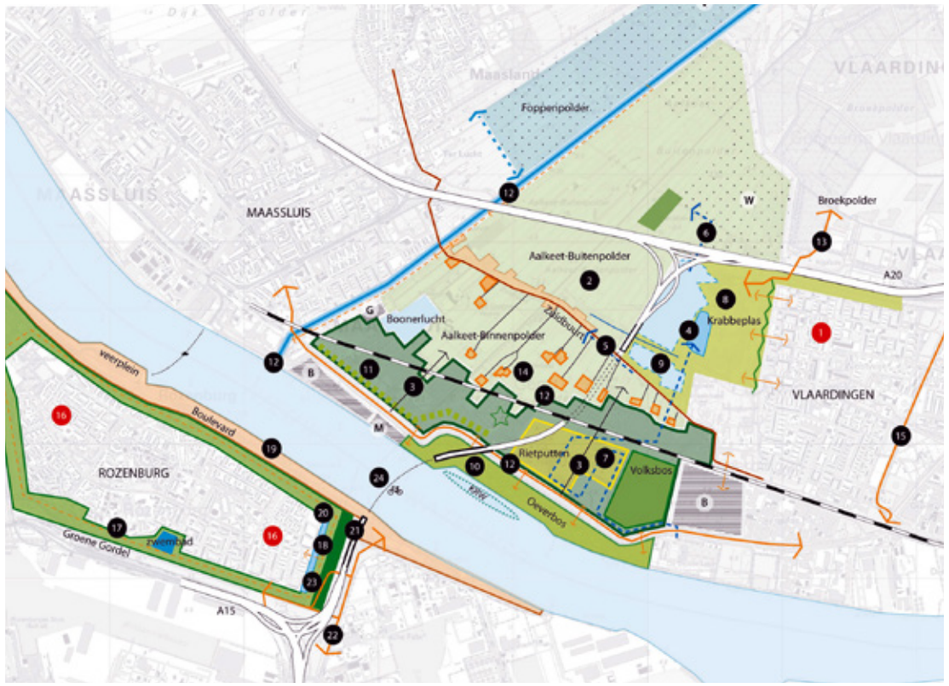


Figure 4. Zoning plan Blankenburgverbinding Krabbeplas-West variant and cross-section of the connection. [© wUrck architectuur stedenbouw landschap, © BGSV bureau voor stedenbouw en landschap] / **Figure 5. Agenda map of the regional quality programme Nieuw Waterland.** [© LOF Landschapsarchitecten]



NORTH BANK
1 Aiming for zero balance for air and noise
2 Preserving openness of the polder landscape
3 From Maassluissedijk create more views to the polder
4 Giving Krabbeplas bathing water quality
5 Maintain profile Zuidbuurt with water connection
6 Possibilities for improving water quality and water connections including fish migration
7 Construction of 'water harmonica' in connection with water from sewage treatment plant
8 Further develop the Krabbeplas creation area into a park with an intensive core area and better ac-cess from Vlaardingen
9 Possibilities to explore canoe routes from Krabbeplas
10 Improving functions and layout of Oeverbos: maintaining continuous recreational routes along the tunnel mouth, strengthening the quality of Oeverbos as a veranda along the river
11 Design of nature development and fauna passage where possible in combination with water development
12 Improving recreational connections between parts of the area and to the surrounding area
13 Improving the Krabbeplas-Broekpolder connection
14 Protecting cultural history and archaeology and making it visible
15 Measures for cross-connections Marathonweg

SOUTH BANK
16 Aiming for zero balance for air and noise
17 Strengthening and preserving the Green Belt Rozenburg, including redevelopment of the swimming pool location, around Rozenburg
18 Layout of the eastern edge of Rozenburg, part outside the scope of the Blankenburg connection, possible adjustment of the route of the flood defence in relation to a noise barrier, strengthening the ecological value of the eastern edge
19 Preserving and strengthening the Boulevard
20 Water management in addition to water compensation
21 Shaping the tunnel mouth node, in such a way that continuity of the Boulevard is guaranteed
22 Improving slow traffic connections between parts of the area and to the surrounding area
23 Relocating or maintaining sports facilities in the eastern edge
24 Investigating the usefulness and necessity of a bicycle tunnel

SPATIAL POLICY
B New business park
G Greenhouses out of the polder
M New cemetery Maassluis
V Vlietlanden
W Meadow bird area

ecological richness – from old farmhouses and monumental areas to natural water systems – all of which demanded sensitive design responses. It enriched and optimized the design process and provided better information for decision-making.

Blankenburgverbinding as favourable option – The Blankenburgverbinding and the Krabbeplas-West variant were ultimately selected in 2013 over the Oranjeverbinding (Ministerie van Infrastructuur en Milieu, 2013). An analysis and evaluation based on a mandatory social cost-benefit analysis (SCBA) showed that the Blankenburgverbinding could handle twice as much traffic as the Oranjeverbinding with an improvement of vehicle lost hours (VHL) of 54% - 64% for the Benelux corridor, as compared to 26% - 43%. Also, the cost and the cost-benefit ratio were better than for other variants. Krabbeplas-West was the variant with the least interruption of the landscape and cultural-historical cattle pasture area and offered a recreational and urban run-off area for Vlaardingen. The impact of noise and negative impacts on natural areas would be mitigated and compensated. Overall, this was an effective solution that also contributes to spatial quality and was strongly favoured by regional stakeholders. The budget was fixed to 1,154 million euros (prices 2013), which also included 25.5 million euros for co-financing measures for regional embedding of the connection outside the scope of the project and the requirements of environmental law with which the project must comply. When compared to the so-called mid-variant an extra 230 million euros was needed for the proposed land tunnel (180 million euros) at the Zuidbuurt area and for the sunken connection with the A20 (50 million euros). However, the Infrastructure fund offered 843.4 million euros, which resulted in a deficit of 311 million euros that must be financed by temporary toll yields. With the decision for the Krabbeplas-West variant the MIRT study phase ended. [Social Cost-Benefit Analysis, page 200]

As a next step the legally mandatory and extensive environmental impact assessment (EIA; MER in Dutch) started, together with a further elaboration of the Krabbeplas-West variant and its impact. This was in preparation for the so-called Ontwerp Tracébesluit (Draft Route Decision) – a preliminary decision by the minister, in which the effectiveness and impact of the variant on a broad range of criteria were documented, and open for public consultation. After the ministry's response to the consultation the decision finally received legal status early 2016 (Ministerie van Infrastructuur en Milieu, 2015). The main conclusion according to the EIA was that the variant had mostly positive effects on traffic, noise, and soil quality. For certain aspects negative effects were foreseen concerning external safety, nature and landscape, cultural-historic and spatial quality. These should be mitigated by additional measures and compensation. A Vormgevings- en Inpassingsplan (Design and Integration Plan, VIP) was also part of the elaboration; here, the design of the roads, connections, tunnels, viaducts, and a small aqueduct were functionally and spatially integrated in the road network, landscape and natural environment (Figure 4). This VIP supported the preliminary and definitive Tracébesluit and served as an assessment framework for further elaboration and for informing the aesthetic programme of requirements, a programme of wishes and requirements regarding the appearance, design and spatial quality of a project, which is a standard part of the tender procedure and the contract for further development and realisation. The elaboration of the designs was carried out by BGSV, wUrck and ZJA Architects & Engineers. [Procurement of Infrastructure, page 102]

Parallel to the ministerial procedure in the period 2013-2015, regional stakeholders had developed a complementary regional quality programme for the area, called Nieuw Waterland. This focused on the recreational, ecological and user experience of the area and matched the budget provided by the ministry which had reserved 25.5 million euros, up to a total of 51 million euros (Figure 5). The programme, developed under the supervision of LOF Landschapsarchitecten, comprised a landscape plan, measures for net zero emission air quality and noise, and measures to improve the urban network (MRDH vervoersautoriteit et al., 2015). The programme prioritised 24 issues for the area to address and to resolve, e.g. improving the water quality of the Krabbeplas, turning the Krabbeplas area into a



Figure 6. The immersion of one of the concrete tunnel elements of the Maasdelta tunnel. [© Rijkswaterstaat, Topview Luchtfotografie] / **Figure 7. Tunnel construction work on both the north and south banks.** [© Rijkswaterstaat, Topview Luchtfotografie] / **Figure 8. The sunken road along Krabbeplas and entrance to the Holland tunnel with the ventilation systems 'disguised' as sheds in the Zuidbuurt.** [© Stan Wanders] / **Figure 9. Entrance to the Maasdelta tunnel towards the A15 on the south bank.** [© Stan Wanders]





park, and making recreational connections within the area at the northern bank. On the Rozenburg side the continuity of the boulevard at the tunnel entrance was one of the issues to resolve.

The Krabbeplas-West variant which was realised between 2018 and 2024 by the consortium of Ballast Nedam, DEME, and Macquarie Capital. This required the mitigation of the cut-through of a historical landscape route with farmhouses in the Zuidbuurt area that would fragment a large area. The construction of the Holland tunnel, as a deepened land tunnel covered with soil, allowed the new infrastructure to pass under sensitive areas without disrupting heritage or ecosystems. The deepened road section for the A20 connection also contributed to less visual disruption of the landscape and less noise. Technically, the Maasdelta tunnel under the waterway – locally named Scheur – posed significant challenges (Figures 6–7). As an immersed construction it required precise engineering to manage conditions, for example to withstand wind and current forces during immersion and ensuring long-term structural integrity. Adverse weather delayed early attempts at immersion, and the final success was achieved only on the third try. Despite these difficulties, the land tunnel solution underscored a commitment to preserving both cultural, landscape, and environmental values – where spatial continuity and cohesiveness of the area and an undisrupted water system are fundamental to secure these (Figures 8–10). Due to its location close to the recreational and residential area in Vlaardingen, a solution was needed to reduce noise pollution and to hide the road from view. Low-noise asphalt and reeds around the Krabbeplas area addressed these issues.

Infrastructural interventions: Spatially, system-wise and - most importantly - socially integrated

Integration went beyond the building of the connection. The initial NWO project for a motorway ultimately resulted in the Blankenburgverbinding, as a multi-functional infrastructure and spatial system design. The integration concept and regional quality program expanded the scope. Collaboration with the Delfland water authority enabled redirection of wastewater to improve local water quality of the Krabbeplas. Municipalities contributed to the development of recreational spaces, linking infrastructure with liveability. These decisions were not add-ons but core components of the landscape, emerging from a shared vision shaped by diverse stakeholders. The intervention scale of the project also shifted. Initially focused on the A24 motorway as a new link in the transport network, the planning extended to consider regional connectivity and landscape integration. Negative liveability effects, ecological restoration, and water management were coordinated through a systems approach. This holistic planning and design approach, with on-going adjustment and collaboration, ensured that infrastructure became a catalyst for sustainable development rather than a barrier – informed by involved stakeholders. [Benefit-Oriented Design, page 276]

A unique aspect of the dedicated participative process was the conscious effort to avoid framing the project solely around civil engineering concerns. While technical feasibility remained essential, civil engineers were engaged early as consultants to explore possibilities, rather than to deliver pre-defined solutions. The primary planning questions – the ‘what’ and ‘why’ – preceded the ‘how’ of design and construction. This sequence allowed for open dialogue and flexible outcomes. Tools like the Omgevingswijzer – an environmental indicator on sustainability themes – provided structure to this process. The tool encouraged systematic reflection on issues like ecology, water, energy, and materials, helping stakeholders articulate and discuss ambitions and to assess existing conditions. More than a checklist, it fostered an interactive design setting attuned to long-term sustainability. [Environmental Indicator, page 178]

Design as a process became a central theme. Communication, visualization, and shared understanding were emphasized, all through interactive design and co-creation. Community-generated ideas were not sidelined; they were central. In fact, the two final design options emerged from the local context, sometimes prompting external critiques that the project offered too few variants compared to what is typically expected in such infrastructure planning processes, where a larger



Figure 10. Construction of the Holland tunnel near Zuidbuurt. [© Rijkswaterstaat, Topview Luchtfotografie]

set of alternatives is the norm. Yet the simplicity was an intentional product of focused, participatory design.

For the area scan independent mediators were hired to manage an open and constructive participatory process in which local people felt comfortable and were invited to bring in their concerns and ideas. The attending experts had a serving role instead of a leading one, as usual. For the regional quality program – with mainly institutional stakeholders – a trusted process manager was hired, a landscape architect who was able to manage complex stakeholder dynamics. For both activities involvement of independent process managers was crucial for the credibility and coherence of the participatory process, allowing for smoother coordination between diverse actors like laypeople on the one hand and institutional parties on the other hand, including Rijkswaterstaat, local governments, water authorities, and design professionals. Visual tools were developed to make design proposals accessible and tangible, fostering deeper engagement. Perception played a major role in shaping the whole project. Initially, resistance and NIMBY attitudes prevailed. Over time, as people were engaged meaningfully, the project shifted from being a government imposition to a shared regional effort. The motorway was no longer just a road but part of an integrated vision for mobility, ecology, and quality of life. In terms of added value, the project delivered more than transportation improvements. It contributed to recreational networks, enhanced water quality, and supported local identity. Trees were planted along banks, not by the main contractor, but by Staatsbosbeheer (Forestry Commission) whose core competencies included landscape and ecological work. This division of responsibilities acknowledged the limitations of any single actor and emphasised the power of coordinated expertise and collaboration.

The complexity of the Blankenburgverbinding was both technical and social. Groundwater management, tunnel construction, and climate resilience posed engineering challenges. But coordinating diverse interests, managing expectations, and sustaining commitment over more than a decade required a sophisticated process design. Co-ownership emerged as a key strategy – not to

dilute responsibility but to distribute it wisely. Each stakeholder contributed where they had the most expertise, creating a mosaic of shared responsibility. The final success of the project came from this systemic approach. The window of opportunity that opened through years of planning was seized effectively because the groundwork of relationships, shared values, and mutual trust had been laid. From water purification strategies to mobility connections, from tree planting to stakeholder engagement, the project illustrates how infrastructure can function as a unifying platform.

Integration as focal point of perspectives

The Blankenburgverbinding offers a compelling case of how infrastructure can be reconceptualized not merely as a technical artifact, but as an integrated system of spatial, environmental, economic, and social value. Considering the theoretical framework introduced earlier – emphasizing infrastructure as an interconnected system and analysed through ten critical lenses – this contribution explores how the project aligned with or challenged each perspective. Rather than a conventional linear infrastructure project, the project represents a shift toward adaptive, multi-scalar, and participatory design.

From a *functionality* perspective the Blankenburgverbinding fulfils its core transport objective by linking the A15 and A20 motorways to alleviate congestion, improve connectivity and make the network more robust for the region. However, its technical success is underpinned by more than civil engineering competence; it required sensitive calibration of its path through densely populated and environmentally valuable areas. The Holland tunnel solution was not simply about efficiency, but about preserving spatial, ecological, and cultural continuity.

Performance was understood and addressed in an explicitly operational manner, following Rijkswaterstaat's RAMS criteria (reliability, availability, maintainability, and safety). These considerations were deeply embedded in the project design. The construction phase, including the immersed tunnel method, posed significant challenges due to bad weather and underwater engineering complexities. The entrances of the Maasdelta tunnel are flood-protected by a dike. A robust risk management approach ensured technical resilience. Operational availability and robustness were not an afterthought, but a co-driver of design decisions. The toll system is automated without any disruption in traffic flow by scanning licence plates of passing cars and lorries which bill can be paid afterwards digitally.

The project's planning process is a notable example of *intervention scales*: infrastructure objects, local environment, and regional connection – simultaneously addressing local community needs and broader regional goals. Although its physical footprint is localised, the A24 plays a critical role in the regional and national transportation network and was integrated into wider environmental and recreational strategies for natural area development. The choice for the scope of an area can open a window of opportunity but also lead to missed chances. With the alternative of the Oranjeverbinding in the process, a broader scope was already introduced which was ultimately beneficial for the Blankenburgverbinding.

The project also exemplifies *resiliency and adaptivity*. By embedding water purification infrastructure and accommodating climate vulnerabilities such as flooding, the design reflects a system flexibility to respond to future stressors. The spatial continuation and blending of transport and ecological systems demonstrates a readiness to engage with long-term environmental uncertainties. Closely related is the attention to *sustainability* in the area scan within the participative design. The use of tools like the Omgevingswijzer as an environmental indicator reflects a structured approach to create awareness and to minimise ecological impact, from material selection to energy consumption. Water purification showcases how infrastructure can support environmental regeneration beyond its primary function. Thus, we see that sustainability was not treated as a checklist but rather as a mindset integrated throughout the project. The connection between the new reeded wetland and the Krabbeplas facilitates a natural water purification process for rainwater and its runoff to the lake.

The project gave thoughtful attention to s*patial quality,* as the present and future use and how users experience the area. With its focus on recreation, nature, and an open landscape within a highly urbanised and industrial region, its serves present and future generations. Rather than an isolated motorway, the Blankenburgverbinding acts as a ribbon that weaves through the landscape with sensitivity, honouring heritage and enhancing the area's visual and ecological cohesion. This spatial value-driven integration should be a key departure from any motorway project which cuts through open natural space.

As its mental counterpart, *perception* refers to how the infrastructure is observed and experienced by its users such as car drivers, cyclists and pedestrians, and by neighbouring communities. In the Blankenburgverbinding particular attention was paid to how the project would be seen, felt, and understood from different physical and sensory viewpoints. Design choices such as landscape integration, visual buffers, and attention to continuity in spatial experience helped shape a route that not only functions well technically but also resonate with users' spatial awareness and aesthetic appreciation. These experiential qualities are intricately linked to the project's emphasis on spatial quality.

The project also delivers substantial *added value*: beyond solving mobility and economic issues, it has become a catalyst for ecological restoration, recreational development, and regional placemaking. Integrating water management and recreation created synergies that far exceeded the functional scope of a road. This also questions the motto 'sober and efficient', which usually guides infrastructure projects by the nowadays called Ministry of Infrastructure and Water Management, and Rijkswaterstaat as its executive body. The project shows that such a motto should not be an excuse for delivering a "gloomy and mediocre design", as one of process mediators of the participative design process explained. This also related to the justification of costs. How to justify the investment of the Holland tunnel which resulted from the participative design? Would the SCBA, whose result is binding, show a positive financial balance for these types of solutions? A notable element is the toll which serves as a financing mechanism to close the overall project's budget shortfall, including the Holland tunnel and deepened section connected to the A20. At the time of the Tracébesluit, the deficit was initially 311 million euros, determined more by the limitations of the Infrastructure fund (now called Mobility fund) than by the specific content of the project itself. Because the toll is designed to recover this shortfall, it will be discontinued once the required amount – now 315 million euros – has been collected. The expectation is that this will be the case after 25 years. This highlights the financial complexity of integrated infrastructure projects and raises broader questions about how public value and cost recovery are balanced in contemporary infrastructure planning. With the final closure of the project the financial balance was made up, amounting 2,200 million euros, including 20 years of management and maintenance as part of the design, build, finance, and maintenance contract (DBFM) (Rijkswaterstaat, 2025).

The outcomes of the project were only possible due to intensive *collaboration* between stakeholders across sectors and scales pursuing the most suitable solution. Rijkswaterstaat's decision to take on a facilitator role – coordinating between local municipalities, water boards, residents, and academic partners – enabled knowledge sharing and co-design. Initial public opposition, particularly rooted in NIMBY concerns, gradually shifted as the project fostered an inclusive narrative. This change in attitude did not happen by accident – it was cultivated through strategic transparency, early involvement, and sustained communication. The outside-in method, including design sessions and co-creation forums, helped transition public sentiment from scepticism to co-ownership. After finalisation of the project, looking back on the process, from the 700 permit applications only

one permit was challenged by an alternative opinion (Rijkswaterstaat, 2025). With this fact it shows that front-end participation in a project and the will to provide extra budget can contribute to a smoother and time-efficient procedure and realisation. A delay – in procedures and realisation has also a price which must be paid.

The technical *complexity* of tunnels under waterways or in a vulnerable subsurface, the governance challenge of multi-actor coordination, and the socio-political dynamics of stakeholder engagement were not simplified; they were reframed as essential design variables. The integrated design process itself became a mechanism to manage complexity by aligning values, distributing responsibilities, and maintaining a shared vision. Thus, complexity was not avoided but embraced.

The Blankenburgverbinding exemplifies the shift from infrastructure as a linear technical endeavour toward a multidimensional, relational project that embraces spatial, ecological, and social systems. It underscores that success in contemporary infrastructure is not merely a function of cost or efficiency but of how well a project aligns with the lived realities, values, and futures of the communities and environments it traverses.

In a time of climate uncertainty and spatial pressure, the Blankenburgverbinding underscores that integrated design is no longer a luxury – it is a necessity. Infrastructure should adapt more to the environment instead of the other way around. This requires a rethink, as this project shows. Its lessons urge us to move beyond siloed thinking and to embrace infrastructure as a social, spatial, and environmental project – designed with, not just for, the people and places it affects.

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NOTES

1. 'Meerjarenprogramma Infrastructuur, Ruimte en Transport', a multi-year programme for infrastructure, space, and transport in which projects are defined, decisions are prepared and budgets will be proposed at a ministerial level. The Dutch parlement has the formal authority to decide on the programme on a yearly basis.

REFERENCES ■ Chinyio, E. A., & Akintoye, A. (2008). Practical approaches for engaging stakeholders: Findings from the UK. *Construction Management and Economics, 26*(6), 591–599 ■ Frick, K. T. (2008). The cost of the technological sublime: daring ingenuity and the new San Francisco–Oakland Bay Bridge. In Priemus, H., Flyvbjerg, B., & Van Wee, B. (Eds.), *Decision-making on mega-projects: Cost–benefit analysis, planning and innovation*, pp. 239–262, Edward Elgar ■ Llancce, A. O., Lim, Y., Esteban, T. A. O., van Leeuwen, J., & Ninan, J. (2025). From Silos to Synergy: Conceptualizing an integrated infrastructure design for climate resilience in Rotterdam. *Climate Risk Management,* 100691 ■ Ministerie van Infrastructuur en Milieu (2011). *Gebiedsgerichte Aanpak. Inpassing Nieuwe Westelijke Oeververbinding.* Slotdocument Participatie in Meedenktafels. Ministerie van Infrastructuur en Milieu ■ Ministerie van Infrastructuur en Milieu. (2012). *'Als je doet wat je deed, krijg je wat je had'. Publieksparticipatie in de praktijk.* Ministerie van Infrastructuur en Milieu ■ Ministerie van Infrastructuur en Milieu. (2013). *Rijksstructuurvisie Bereikbaarheid Regio Rotterdam en Nieuwe Westelijke Oeververbinding.* Ministerie van Infrastructuur en Milieu ■ Ministerie van Infrastructuur en Milieu. (2015). *Tracébesluit / MER Blankenburgverbinding.* Hoofdrapport MER. Ministerie van Infrastructuur en Milieu ■ Metropool Regio Rotterdam-Den Haag Vervoersautoriteit, Provincie Zuid-Holland, Rijkswaterstaat West-Nederland Zuid, het Hoogheemraadschap van Delfland, gemeenten Rotterdam en Vlaardingen. (2015). *Regionaal Kwaliteitsprogramma Blankenburgverbinding.* MRDH ■ Ninan, J., Lim, Y., De Boer, H., Pesamaa, O., Van Acker, M., Schwab, E., Bernsteiner, J., Soderholm, P., & Hertogh, M. (2024). Embracing multi-functionality in European infrastructure projects: A system of systems perspective. *Sustainable Futures.* 100308 ■ Ninan, J., Mahalingam, A., & Clegg, S. (2020). Power and strategies in the external stakeholder management of megaprojects: A circuitry framework. *Engineering Project Organization Journal, 9* (1), 1-20 ■ Rijkswaterstaat. (2025). *Gebiedsgericht werken aan Ruimtelijke kwaliteit, Best practices.* Rijkswaterstaat, Ministerie van Infrastructuur en Watermanagement.

LESSONS

PARTICIPATIVE DESIGN FOR SPATIAL QUALITY AND ADDED VALUE

The Blankenburgverbinding reveals a transformative approach to infrastructure planning – one that emphasizes co-creation, contextual understanding, and multidimensional value. A few core lessons emerge that can inform future projects of similar scale and complexity.

– ***Early-stage stakeholder involvement is essential.*** By engaging residents, municipalities, cyclists, and businesses before design solutions were drafted, the project built trust and a shared sense of ownership. This outside-in approach not only reduced opposition but shaped more context-sensitive outcomes, such as the Holland tunnel and integrated water systems. It demonstrates that infrastructure legitimacy is earned, not imposed. Answering 'why' questions helps to define purpose and common ground, while the 'how' explores directions and elaboration delivers solutions, as the 'what'. This method also determines the roles, expertise, and moments for which internal or external professionals must get on board.

– ***Formulate an integrated and value-rich definition of the design objectives beyond transport functionality.*** Identify a broader set of ambitions relating to functionality, sustainability, spatial quality, perception, and beyond, helping to balance competing priorities. Rather than optimizing for transport alone, the project uncovered added value across ecology, recreation, and community development. Viewing the project as a spatial rather than purely technical intervention opened pathways to align diverse interests under a common vision. This approach could be also beneficial for smaller infrastructure projects.

– ***Interdisciplinary collaboration brings both richness and friction.*** Aligning technical, environmental, and social expertise requires process design as much as engineering skill. Navigating different languages of practice – between landscape architects, civil engineers, local stakeholders, and policy actors – demands strong facilitation and shared purpose. Another key insight: taking more time to design saves time during construction and adds long-term value. Even in smaller projects, early design effort pays off. The project shows that neither top-down nor bottom-up alone is sufficient and a balance is essential. Also, while extended discussions were sometimes seen as delays, they ultimately built trust and delivered more durable outcomes. In infrastructure, long-term thinking often requires patience upfront.

– ***A collaborative attitude and co-creation played a pivotal role in building understanding, commitment, and project legitimacy.*** Initial resistance rooted in NIMBY sentiments was gradually transformed through transparent dialogue, visible progress, and trust-building figures and patterns. This collaborative learning process framed by the shift from 'decide-deliver-discuss' to 'discuss-decide-deliver' helped stakeholders move from viewing the project as a threat to seeing it as an opportunity for area enhancement.

– ***Understanding integrated design requires interaction between practice and university.*** Providing cases, guest lectures, and graduation projects from practice played a bridging role. Collaborations with TU Delft and the minor programme Integrated Infrastructure Design (IID) supported critical reflection and methodological rigour, while giving students and professionals room to evaluate new frameworks and approaches and to develop awareness about a multitude of disciplinary perspectives, as the applied lenses embody. This highlights the importance of theoretical grounding in real-world complexity.



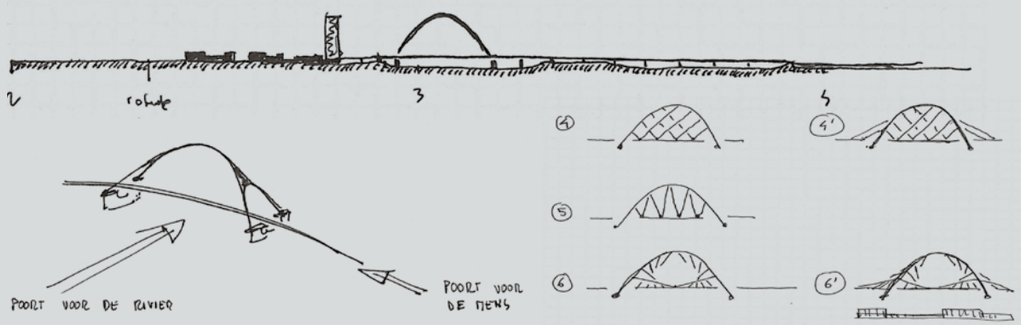
FEATURED DESIGN: DE OVERSTEEK / THE CROSSING

SHAPING FORM BY BALANCING FORCES

Designing a bridge involves many technical and aesthetic aspects. But bridges are also part of day-to-day life, while also creating memories of a place. To what extent can the design of a bridge connect both time and space – functionally and culturally?

Characteristics

This city bridge for all traffic spans the river Waal at the city of Nijmegen and accommodates four vehicle lanes, one reversible lane, one combined cycle and pedestrian path, and an emergency lane. It is one of the three bridges in the city, alongside the Waalbrug (1936) and a railroad bridge (1879). De Oversteek has a total length of 1,195 m, a width varying between 25 and 30m, a height of 60 m and a navigation clearance of 14.5 m.



The 285-meter-long single steel arch spans the river, providing a 235-meter-wide navigation passage. The bridge is a bowstring arch integrated with a slender, stiff deck, supported by sixty diagonally crossed steel cables to ensure an efficient and optimised distribution of forces. The single arch minimizes substructures, reducing both the amount of steel used and long-term maintenance costs. The arch and deck weigh 6,100 tonnes and are airtight, preventing corrosion and maintenance costs. A distinctive feature of the bridge is that the arch cleverly conceals its skewed alignment relative to the riverbanks.

The approach spans consist of concrete arches in a gentle curve, with the southern approach span measuring 230 m and the northern approach span 680 m. In total, they comprise twenty concrete arches of 42.5 m each, clad in characteristic local masonry. Thanks to their continuous arch structure, the approach spans require no expansion joints, as vertical thermal expansion is absorbed within the system. The northern approach also spans a bypass canal, part of the Dutch national *Room for the River* program, which alleviates high water levels that previously caused flooding in Nijmegen's city centre. The bridge was constructed for 148 million euros under a design, build and maintain contract for 25 years.

Significance

The city's ambition for the bridge was defined by four key qualitative criteria: 1. A highly visible and perceivable river landscape from both the bridge and riverbanks. 2. A design that integrates

Previous pages: De Oversteek at night, seen from the south bank. [© Thea van den Heuvel] **/ Right page: De Oversteek, one of the three city bridges over the Waal River.** [© Rijkswaterstaat, Johan Roerink (top right) / © Ney Poulissen Architects & Engineers, Stijn Bollaert]



seamlessly with Nijmegen's existing cityscape and future spatial developments. 3. An artistic and integrated work of contemporary engineering and design. 4. High-quality public spaces on and beneath the bridge. These criteria allowed for substantial design freedom and enabled early consultation and dialogue with the commissioner ahead of the tender procedure.

The arch typology was chosen both for its structural efficiency and to create continuity with the Waalbrug which, when completed in 1936, was the longest arched bridge in Europe (244.5 m span). Nowadays De Oversteek is Europe's longest single-arch bridge; it won the National Steel Award in 2014.

Beyond its structural and aesthetic contributions, the bridge significantly improves traffic flow by easing congestion on the Waalbrug and in Nijmegen's inner city. It also enhances the accessibility to the Waalsprong, a major urban development with historic roots dating back to the Roman period.

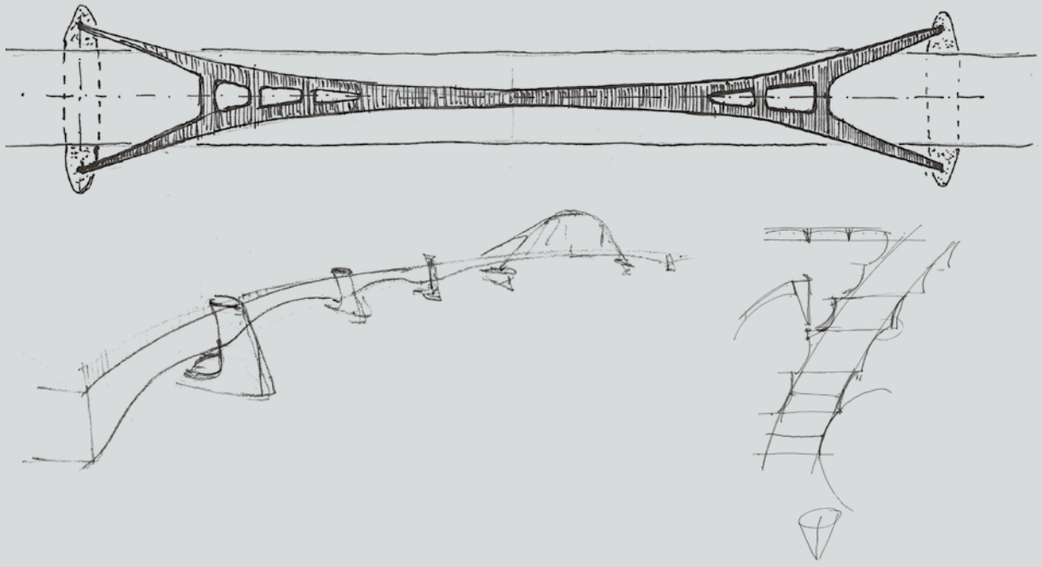
The bridge's name, De Oversteek (The Crossing), honours the 1944 Battle of Nijmegen, part of Operation Market Garden. During the battle, paratroopers from the US Army's 504th Parachute Infantry Regiment (82nd Airborne Division) attempted to cross the Waal in canvas boats to seize the railroad bridge from German forces. Forty-eight American soldiers were killed by enemy fire during the crossing. This sacrifice is commemorated by the art installation *Lights Crossing* by Atelier Veldwerk. The work consists of 48 pairs of lampposts along the bridge, symbolizing the fallen soldiers. Since 19 October 2014, a veteran soldier performs the Sunset March every evening, walking in step with the sequential illumination of the lights.

Hans de Boer, TU Delft & Joris Smits, Ney & Partners

LOCATION: Nijmegen, Gelderland ■ **COMMISSIONER/CLIENT:** Nijmegen City Council ■ **ARCHITECTS:** Laurent Ney and Chris Poulissen ■ **ENGINEERING:** Ney & Partners, Leonhardt, Andrä & Partner, BAM Infraconsult ■ **CONSTRUCTION:** BAM Civiel, Max Bögl ■ **REALISATION PERIOD:** 2011–2013.

FURTHER READING ■ Ney, L. (2014). *Nijmegen: Designing the 'City Bridge'*. Van Tilt Publishers.

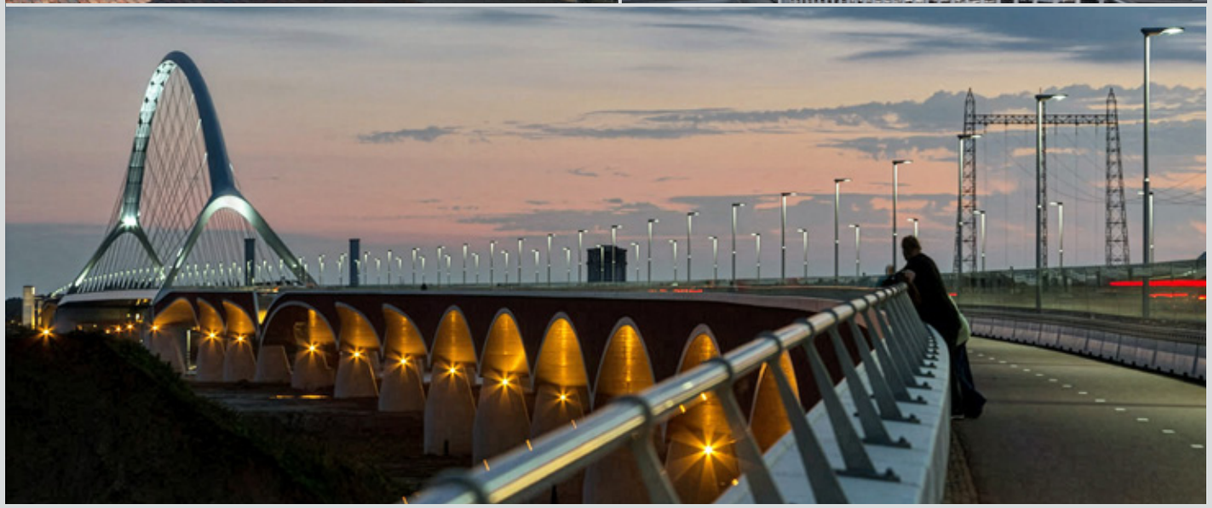
Images right page [© Ney Poulissen Architects & Engineers, Stijn Bollaert / © Fotografie Jacqueline van den Boom (bottom) / Drawings: © Ney Poulissen Architects & Engineers]











METHODS TECHNIQUES STRATEGIES

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Design of Hubs-Game

With the growing attention for sustainable mobility, public transport stations evolve more into hubs, connecting several transport networks at different scales in one integrated system, embedded in its urban environment. At the same time hubs generate an accumulation of wishes and interests by a broad array of stakeholders. How to find a common denominator and mutual understanding? Can a game with design elements support this?

PURPOSE – Design of hubs is a role-play game for co-creation between various actors (stakeholders) which influence a negotiation process on the design and re-development of a – in this case – station building and the surrounding areas. These actors represent key perspectives in areas such as accessibility, use of space, environmental impact, and financial return.

Within an educational setting the game can be used to simulate realistic negotiation sessions. Lecturers may guide students through complex or 'wicked' problems – challenges that are difficult to define and even harder to resolve. Students can experience the roles of various stakeholders, allowing them to understand conflicting priorities, values, and goals. By engaging in these exercises, they gain insights into how different stakeholders might approach the same problem and what it means to 'design for each other's values'. The process not only nurtures empathy but also helps define a common agenda or design brief for a station as hub. Any other project could benefit in a comparable manner to explore the ideas and position of relevant stakeholders.

APPROACH – The game replicates urban dynamics and real-world interactions to create a rich, reflective learning experience. Before the game begins, participants are asked to choose a stakeholder type and investigate and understand their stakeholder's priorities, policies, and position regarding the transformation of the station site. The cards used throughout the game are:

1. *Stakeholder cards:* these contain the stakeholder's name, description, social role, and key values. Players fill out their specific goals and assign values to the variables *accessibility*, *use of space*, *environment*, and *profit*.
2. *Action cards:* each stakeholder gets 10 to 15 cards. These include: 1 destructive card (mostly negative impacts), 1 booster card (mostly positive impacts), 6 regular cards (mixed effects), and blank cards for user-defined actions.
3. *Scoreboards:* these display the four variables with a scale from -10 to 10. As players use action cards, scores are updated to reflect the impact on each variable.

The game includes several rounds or moments in a workshop setting for reflection, allowing for discussion and testing of different future scenarios in a controlled and creative environment.

Manuela Triggianese, TU Delft

APPLICATION
Lecturers, researchers, students, and professionals can all benefit from using this tool offered in a workshop setting to collaboratively design urban hubs. Participants are expected to define a shared vision or agenda for a particular site by the end of the game session. In this way, the game functions both as an assessment tool as well as a participatory design method for urban transformation.

LIMITATIONS
The game is supposed to be of use in a 'front-end' situation exploring challenges, issues, and opportunities around a (potential) hub ahead of the formulation of a design brief. Its outcome is not a particular design but a better understanding of stakeholder dynamics whereby design and policy measures are instrumental to the process.

FURTHER READING ■ WALK-IN (acronym: Widening sustAinable mobiLity networKs): *Impact on Nodes*, NWO KIEM GoCI 2020–2023 [GOCI.KIEM.01.045]. A video of the game can be found on YouTube: youtu.be/inFjSfr1RiO?si=x9tHcYF9JcUYBeFc.





Design of hubs is a serious game developed for the Master module City of Innovations at TU Delft Faculty of Architecture and the Built Environment, Department of Architecture. The tool was developed in collaboration with the blended learning advisor Marvin Soetanto and Zeynep Yanikomeroglu. It is part of the Walk-In research project funded by NWO-KIEM (GOCI.KIEM.01.045) and led by Manuela Triggianese. [© Laura Simonsen and Zeynep Yanikomeroglu / © Halina Zarate (top-right) / © Manuela Triggianese (bottom)]



Integrated Transition Strategy

Many long-term transition strategies for various systems are explored by sector and developed from a 'what-if' approach – in which a representation of a certain situation in the future takes centre stage. But how do these sectoral transition strategies relate to each other for a specific area? Is there enough space available to realise them all? How to reveal potential conflicts or opportunities? How to coherently integrate different system transitions that inform policymaking?

PURPOSE – Transition strategies, for instance for the water, mobility, or energy system, can be developed at varying scales, from local to regional or (inter)national. Often, they are developed sectorally and display little relation to other relevant transition strategies in the same region, often resulting in conflicting spatial claims and missed opportunities for alignment. A *research by design* approach helps to spatially project alternative sectoral long-term transition strategies in an early stage to explore potential conflicts or opportunities. This not only confronts different sectoral transition strategies with each other but also develops and evaluates different potential integrated strategies and pathways. So-called 'basic attitudes' are formulated from which choices for measures and interventions can be derived to define cohesive, integrated long-term transition strategies – in which different sectoral transition options are combined, and spatial claims are negotiated. Acquired insights can inform short-term decision-making aligned to the long-term perspective.

APPROACH – The approach distinguishes the following steps:

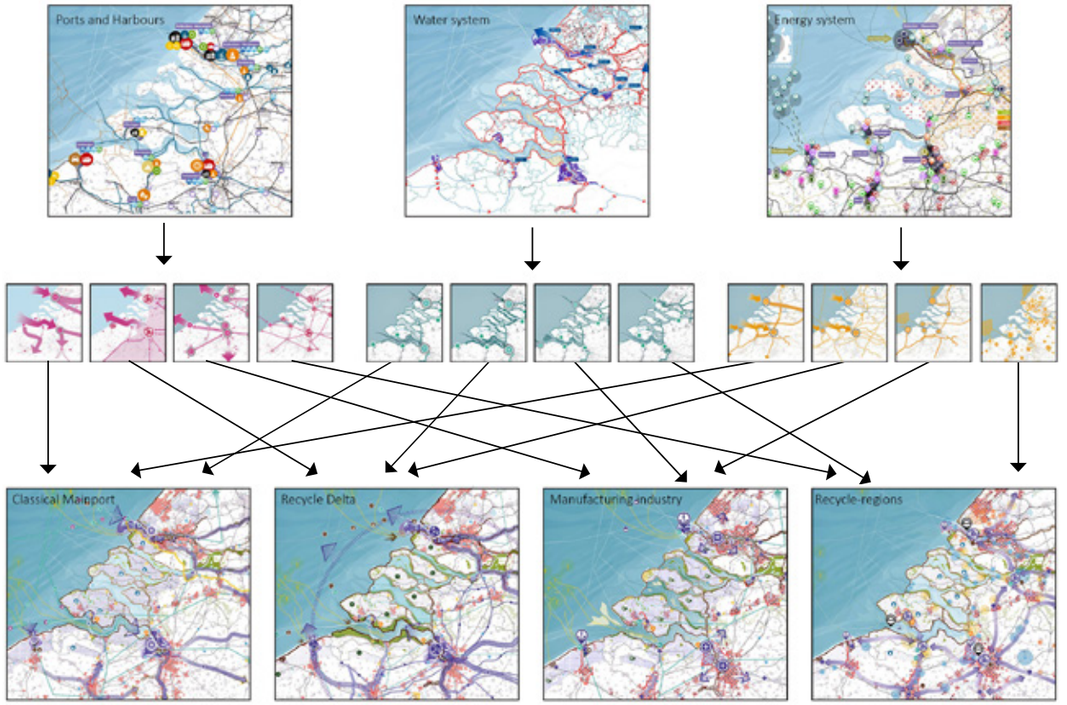
1. First, the focus area as well as the relevant systems – like water, transport, or energy – and its transitions are selected (for instance, climate adaptation, energy transition, or circular economy).
2. Based on desk research and a first series of joint fact-finding workshops with experts, maps are made of each current system and its foreseen transition. They describe its spatial characteristics and relevant underlying mechanisms, and the current and expected trends are outlined, along with potential interventions.
3. Three to four basic attitudes are formulated based on their outlook on priorities and goals, and considering relevant decision-making levels (for instance, are economic growth or sustainability goals the main drivers? Are national or local politics dominant in decision-making?). Narratives are derived from these attitudes for each system transition, which includes a selection of measures in space and time.
4. During an integration workshop, for each basic attitude the narratives per system transition are combined in a long-term perspective and integrated transition strategy. In this, (spatial) conflicts or opportunities may occur. The way these are addressed can differ per attitude, since different attitudes can result in other priorities.
5. Ultimately, decision makers discuss the results.

APPLICATION
Useful for areas where different transitions are developed in parallel, each with their own spatial impact. The approach integrates sectoral knowledge, measures and strategies and visualizes its spatial impact to reveal conflicts or opportunities. Alternative long-term perspectives and their integrated transition strategy provides insight into the coherence of measures and consequences for spatial use.

LIMITATIONS
The approach requires the involvement of experts with in-depth system knowledge and a good understanding of its transitions. Although time-consuming its insights are beneficial for further policy development.

Anne Loes Nillesen, TU Delft

FURTHER READING: Nillesen, A.L., Swinkels, S., Kuipers, B., Verhoestraete, D., & Emmeri, M. (2024). *Toekomstbestendige havens in de Vlaams-Nederlandse Delta. Ruimtelijke langetermijnverkenning.* College van Rijksadviseurs (CRA).



The top row represents the different existing systems and their developments present within an area like the Flemish-Dutch Delta. As a response to these, basic attitudes are formulated based on an outlook of priorities and goals, leading to narratives and measures for a system, as shown in the middle row. The bottom row shows that an attitude finally results in one integrated transition strategy as a long-term perspective, informed by choices and pathways of measures for the included systems. In this case four attitudes and corresponding transition strategies emerge. [© Defacto Urbanism] **/ Port of Rotterdam: industry at the Maasvlakte.** [CC Kees Torn]



Land Use and Transport

Getting to work, school or shops is intrinsically part of our daily affairs. The need for mobility forces us to make choices about the transport services we must take. Conversely, the question arises whether a destination such as a school is favourably located. Where to settle?

PURPOSE – Land use and transport are intertwined aspects of society, which have a symbiotic relationship. Early settlements were at riverbanks or crossroads of trade routes, accessible by ship or cart. As the population and trade increased, settlements expanded into villages or cities. With the coming of transport means like the train, car, and airplane, the world has become at the same time smaller due to shorter travel times and bigger due to a mobility larger range. Our space to move around is defined by human activities and the related need for space and mobility, which determines the geographical distribution of activities, the availability of transport means and services, and the necessary infrastructure networks. These support a prosperous society because of the economic meaning of transport and the agglomeration benefits of accessible urban functions and activities. However, suburbanisation and car use have led to highly urbanised and fragmented areas, busy motorways with high emissions, and subsequent stress to the environment, landscape, and ecology.

Activities – like living, working, shopping or recreation – go hand with *accessibility,* a key factor in the relationship and dynamics of land use and transport (Figure 1, Table 1). Accessibility can be understood as the ability to move timely and easily to many locations from one point of origin (1 : n) or as a destination being well accessible from many locations (n : 1). Residents want to know if work, amenities, or recreation are accessible by bike, public transport, or car. For a retailer or manufacturer, the choice of location is important, because it determines whether clients, employees, and suppliers can reach their destination timely and easily. These questions are also relevant when buying a house or investing in a building and for the land value it represents. New local activities that are established stimulate the activities of others who visit the location, which will 'close the loop'.

APPROACH – The conceptual model of land use and transport in figure 1 can be helpful in two ways (Wegener & Fürst, 1999):

- *Descriptively*: the land-use transport feedback cycle can help us understand the mechanism by which some neighbourhoods, cities, or regions are well accessible and attractive for residents, employees, visitors and investors, and therefore flourish, while others suffer by congestion or limited connections and decline. It can also shed light on the performance of the *daily urban system* and the extent to which an agglomeration benefits (or not) due to its urbanity.
- *Prescriptively*: policy and design can contribute to improve accessibility by developing transport services and infrastructure and stimulating urban development. This requires optimal collaboration between stakeholders responsible for transport policy and spatial planning, since both are characterised by separate responsibilities, long lead times, high investments, and ownership issues.

APPLICATION
Spatial planning, urban development, real estate and business park development, transport services and infrastructure development.

LIMITATIONS
Land use and transport depend on planning, regulations, funds, and decision-making by public actors and the willingness by private actors to invest. Interests need to be aligned within a long-term vision and commitment.

Hans de Boer, TU Delft

FURTHER READING ■ Baggen, J.H., & Van Ham, J.C. (2019). *Het transportsysteem.* Delft Academic Press/VSSD ■ Smets, M. (2022). *Foundations of urban design.* Public Space ■ Wegener, M. & Fürst, F. (1999). *Land-use transport interaction: State of the art.* Universität Dortmund, Institut für Raumplanung.

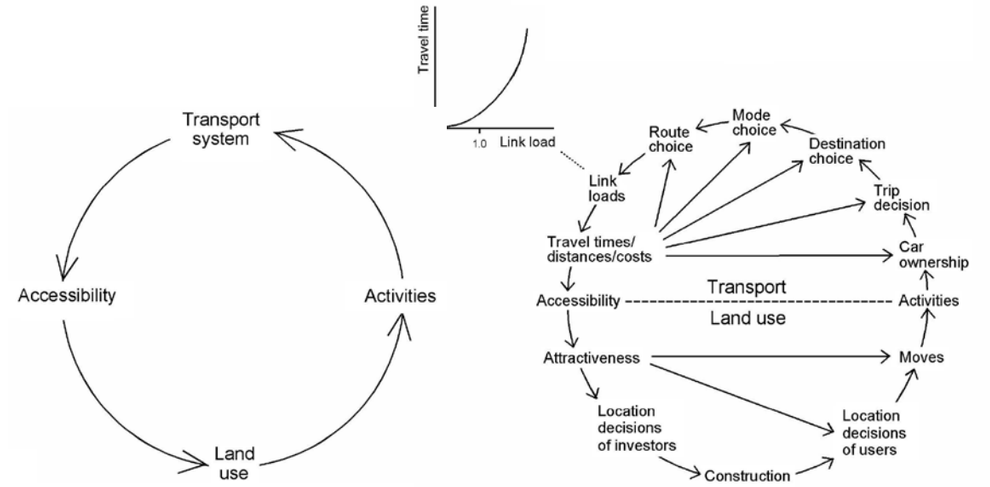


Figure 1. The land-use transport feedback cycle expresses the interrelation and dynamics between the use of space and transport, and vice versa. (© Wegener & Fürst) **Transit-oriented development (TOD) and the x-minute city are related concepts. For example, the urban area development of the Kop van Zuid – a former port location in Rotterdam, now a high-density area with offices, apartments, hotels, restaurants, and cultural spaces – has benefited strongly from the construction of the Erasmus bridge and the metro station Wilhelminaplein. These connect the city center on the northern and Kop van Zuid on the southern riverbank, offering multi-modal accessibility for a vibrant place to live, work, and visit.**

Relationship	Characteristics
Land use ↕ Transport	Density/function mix: dense residential locations do not lead to shorter trips; in fact, work or retail locations with a high density can lead to longer trip lengths. A balanced residential and workplace mix can lead to shorter distances, which can stimulate walking and cycling. High-density locations can provide the critical mass needed for public transport, which can reduce car use. Proximity/scale: attractive public space and a variety of shops and amenities in a neighbourhood can lead to shorter trips and more trips, which can induce walking and cycling. Street, pavement, and cycle path design can support these transport modes, while keeping an eye on spatial quality. Destinations in peripheral locations mean longer trips. Locations close to stations or public transport stops generate more public transport trips. Larger cities and agglomerates benefit most from public transport systems and related trips.
Transport ↕ Transport	Well-accessible locations generate longer and more trips: in case of car accessibility, this will attract more cars, and in case of public transport accessibility more passengers. Travel costs have a major influence on trip distance and frequency and choice of mode of transport. More costs will lead to shorter and fewer trips, as well as alternative transport choices. Car users are not easy to convince about the use of public transport. Travel time reduction by system improvement can lead to longer and more trips and other transport choices. When demand exceeds the capacity of a road or railway connection (network link), travel time will rise exponentially.
Accessibility ↕ Activities	Well-accessible locations with a variety of functions and activities like working, education, and shopping have a higher land value and therefore are attractive for residential development. The better the accessibility, the higher the land value and the faster its development. Locations close to motorways and railway or waterway freight terminals are attractive for logistics and industry. Locations near inner-city (high-speed) train stations are attractive for offices. Retail can profit both from inner-city locations accessible by public transport, as well as peripheral locations that are accessible to cars.

Table 1. Relevant aspects to consider for policy development and design regarding location choice, transport options, and supportive infrastructure in order to stimulate sustainable urban transport (Wegener & Fürst, 1999).

Layer Approach

For deltaic areas, water has been and is essential for existence and prosperity. Trade and agriculture are important economic drivers, while urban development agglomerates around coastal and riverine areas. However, such areas are vulnerable to the effects of climate change. How to protect them, while accommodating growth, and how to balance land use and nature in a cohesive way?

PURPOSE – The layer approach is (by origin) a planning tool to prioritise and coordinate important spatial design-related national governmental themes in the Netherlands in a cohesive way. Its introduction in 1997, as a strategic planning concept (De Hoog et al., 1998), was to answer the question of subsidiarity in planning: what should be the responsibilities on the national level for spatial planning? There was a demand for a boundary-spanning instrument that was scientifically justified, but also politically and socially acceptable, and foremost applicable in practice. It proposed a sequence of three planning layers in order of importance, which should bring synergy between interventions. On a national scale, the substratum of the soil and water systems with a slow dynamic should be leading; on a regional scale, the networks and infrastructure layer that organises the substratum layer on a faster pace takes centre stage; and on municipal scale, the fastest-changing top layer of occupation plays the central role. This approach can be used as action guide for politicians, planners, and citizens.

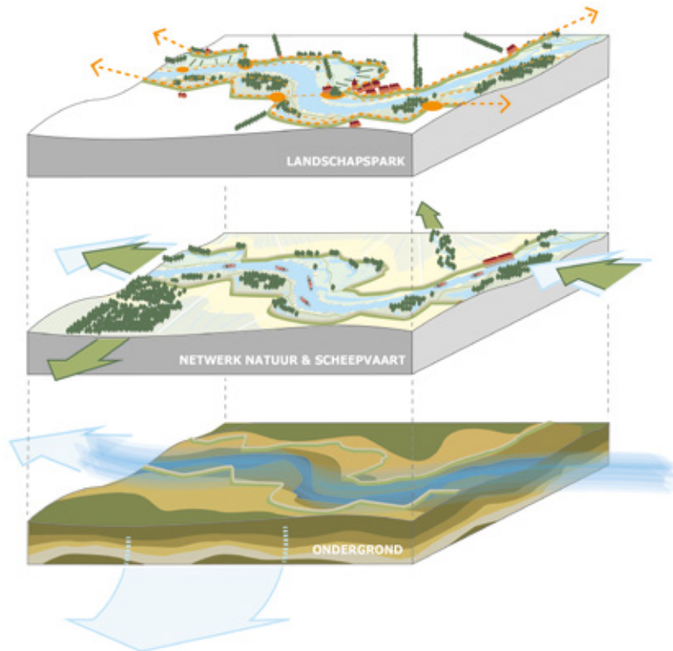
In practice the concept evolved – as the 'layer model' – into a more descriptive and analytic tool to understand space and the interrelationship of layers in specific areas. It came to be used as a foundation for vision development and making plans or designs for the natural system. In this variant, the substratum layer is interpreted as an abiotic environment on which the biotic system reacts. The network and occupation layers are considered as anthropogenic layers. With this interpretation the substratum became a container layer for all distinct aspects of the subsoil system, which makes it static and motionless. Sijmons (2002) sees this as a loss of adaptability of the initial approach at the expense of soil- and water-related challenges like biodiversity and the effects of climate change. It also ignores the initial goal as strategic planning concept.

APPLICATION
As planning tool for coherent decision making at different administrative levels and geographical scales. It also enhances coherence of interdisciplinary design teamwork. Another method is system exploration environment and subsurface (SEES) (Hooimeijer & Maring, 2018).

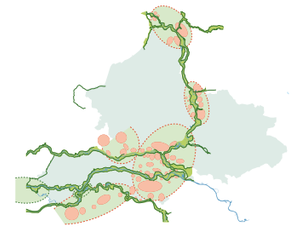
LIMITATIONS
Often mixed-up with the layer model which is descriptive and less specific than the layer approach for which the water system is the starting point for spatial planning. However, as spin-off it developed also as a useful tool to understand the use of space and spatial relationships.

APPROACH – The layer approach defines water as fundamental for all other spatial design-related developments to preserve and improve nature and to secure a flood-proof delta:

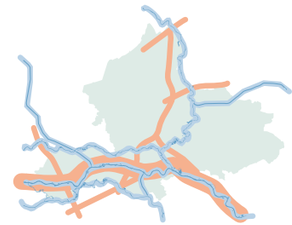
1. *Substratum layer* (planning horizon 20 to 200 years): the water system is pivotal for the condition of land surrounded by water, soil, groundwater, biodiversity, and climate. For this layer, the approach aims at a the balance of biodiversity and nature, a well-performing water system, flood resiliency and eco-engineering. The national government should primarily take the responsibility of this layer. Interventions and infrastructure decisions in this layer should always have preference over or be formative for planning decisions in the other layers.
2. *Network layer* (planning horizon 10 to 50 years): this layer consists of infrastructure corridors, nodes, and energy, including dikes and pump



Layers as guiding principle

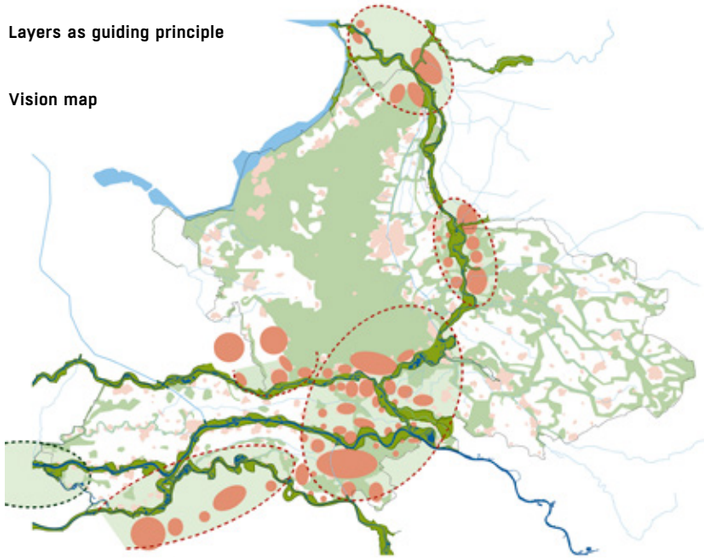


River parks



Navigation network

Vision map





Nature network



Rivers

The province of Gelderland has developed the action perspective 'Panorama Gelderse Rivieren' based on the layer approach. The subsurface forms the so-called first guiding principle that focuses on the development of a future-proof, robust and clean river system. This is the basis for the second guiding principle that focuses on the nature and shipping network. With the third guiding principle, the river creates the basis for a landscape park. As a fourth guiding principle, the province has added the values of quality and individuality. [© Province of Gelderland, Kees van der Velden]

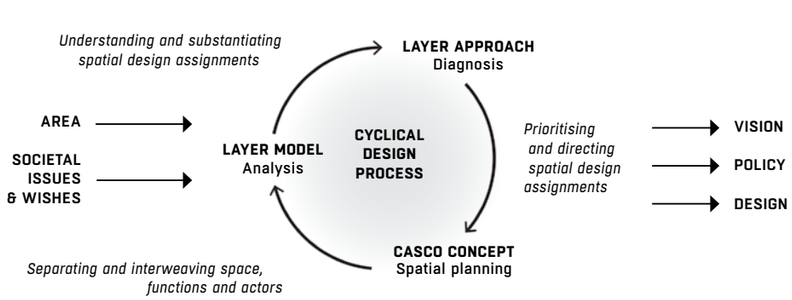
stations for discharge. Nature serves as a corridor, living area and network. This layer falls under the responsibility of the national and regional government and is – in an indirect way – formative for the spatial-social reality.

3 *Occupation layer* (planning horizon 5 to 30 years): this layer revolves around living, working, agriculture, recreation, raw materials, etc. The approach for this layer aims at nature-inclusive use of space including ecosystem services and recreation, while being aware of the risk of flooding and need for evacuation. Spatial claims in this layer are derived from the priorities set by the two other layers.

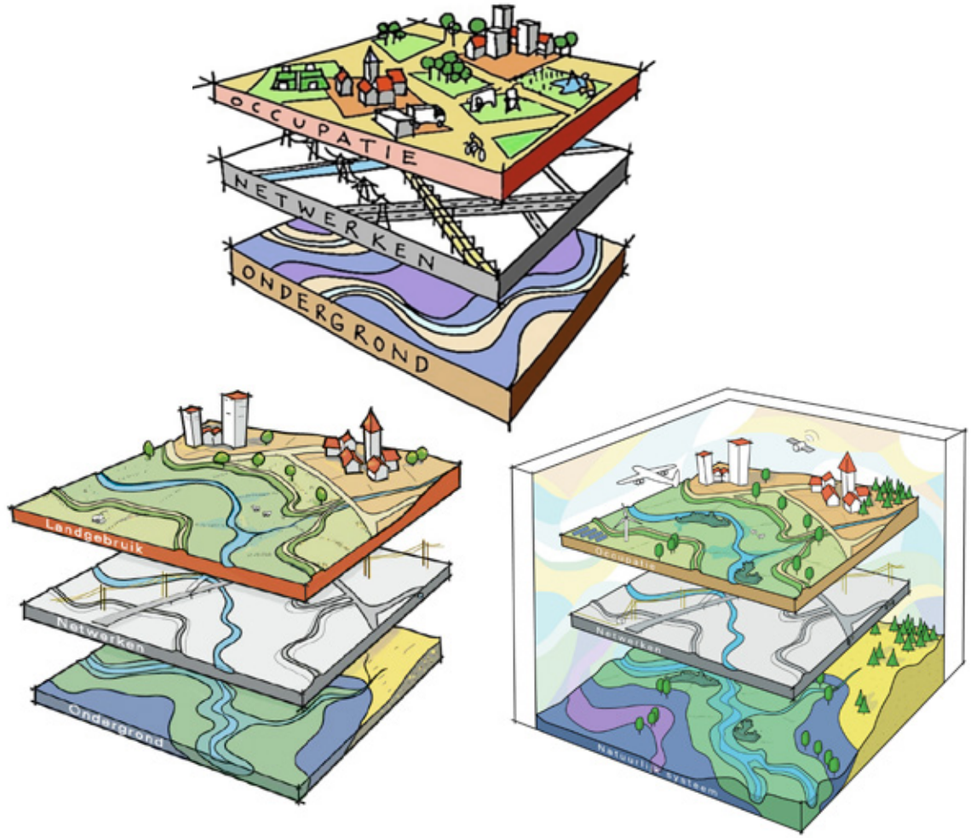
With the renewed attention of the Dutch government for soil and water as key principles for spatial planning and urban development, the layer approach could gain more attention for its focus on cohesive planning and its connection to the water system.

Fransje Hooimeijer, TU Delft

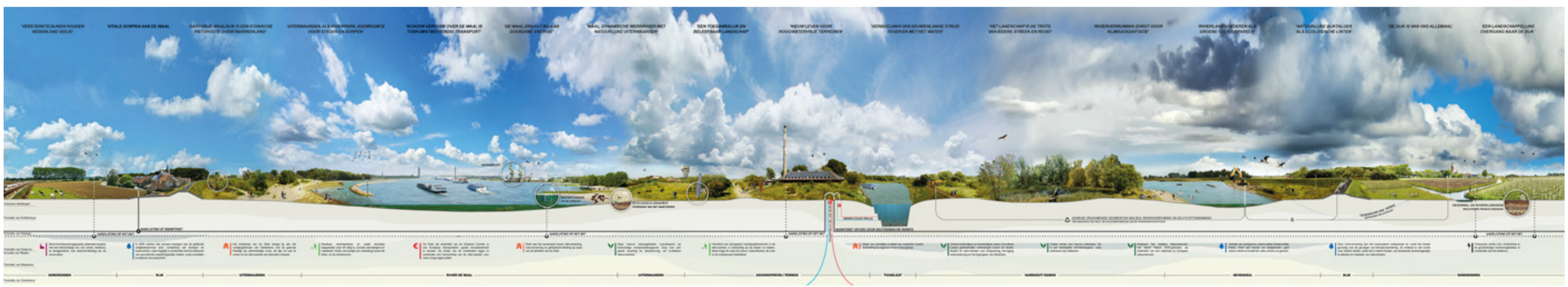
FURTHER READING ■ De Hoog, M., Sijmons, D., & Verschuuren, S. (1998). Herontwerp van het Laagland. In D.H. Frieling et al. (ed.), *Het Metropolitane Debat,* 74–87. THOTH ■ Deltares, BoschSlabbers & Sweco. (2021). Op *Waterbasis; grenzen aan de maakbaarheid van ons water- en bodemsysteem.* Deltares ■ Hooimeijer, F.L., & Maring, L. (2018). The significance of the subsurface in urban renewal. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 11: (3),* 303-328 ■ H+N+S Landschapsarchitecten. (2023). *De lagenbenadering, het lagenmodel en het casco concept. Reflecties op drie instrumenten in het herontwerpen van de Nederlandse delta.* H+N+S Landschapsarchitecten ■ Provincie Gelderland. (2022). *Panorama Gelderse Rivieren. Provinciaal handelingsperspectief.* Provincie Gelderland ■ Sijmons, D. (2002). Met beide benen op de Ondergrond (New adventures of the Layers Approach) in: Sijmons, D. *Landkaartmos.* 010 Publishers.



Position and interrelationship of planning and design tools within a cyclical spatial design process. [© H+N+S]



Three examples show the evolution of the layer model with layers like the layer approach, but from a different starting point and with a different use. The subsurface forms the first layer, the infrastructure networks the second layer and land use the third layer. Top: one of the first examples primarily to distinct the layers. It does not show the relations between the layers. [© Dauvellier Planadvies] **/ Left: the relationships between the layers are expressed, including the water system.** [© BoschSlabbers] **/ Right: the final model redefines the first layer as the natural system and adds the atmosphere.** [© H+N+S] **/ Below: Panorama Gelderse Rivieren: the Waal River.** [© West 8]



Life Cycle Management

How can public investments in infrastructure deliver maximum value – not just today, but for generations to come? This question lies at the heart of life cycle management (LCM), a powerful approach for aligning long-term societal benefits with current decision-making. How can LCM reshape the way we plan, build, and manage our public assets?

PURPOSE – Almost every infrastructure investment made today has long-term cost implications, which are intricately linked to current design choices. Not every solution that meets today's social demands generates the same long-term value, nor does every solution have identical side effects during the operational phase or the same resilience to future change. The purpose of LCM is to explicitly model these life cycle effects – both for existing and newly built infrastructure – and to support decision-making that maximizes long-term social value from public investments.

Traditionally, maintenance, renewal, and improvement projects in public infrastructure are governed by client-contractor agreements specifying deliverables, costs, and timelines. Asset management, in this context, is focused on ensuring agreed performance levels and managing risks within available budgets. Given the inherent scarcity of resources, the focus is often placed on addressing the most urgent current issues – even when this results in significantly higher costs in the long run. Projects are rarely rewarded for exceeding current budgets to achieve future savings. This can change if decision making is guided from the outset by a life cycle perspective.
LCM expands the scope of decision making by adding three key parameters: 1. the expected impact of investments on life cycle costs, 2. life cycle risks, and 3. life cycle performance.

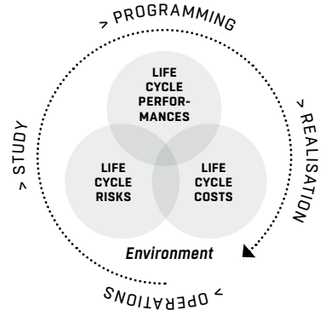
APPROACH – LCM involves managing life cycle costs (LCC), life cycle risks (LCR), and life cycle performance (LCP) in a dynamic environment (Figure 1 and 2). It encompasses organisational behavior (how organisations can act in accordance with LCM principles), culture (how individuals can be encouraged to adopt appropriate behavior), processes (how to structure workflows that support LCM), and technical aspects (how to quantify LCM parameters, what technologies are needed to support LCM processes, and how to express technical complexity through clear, comparable LCM metrics). A wide array of methods is available to support LCM:
(a) cost calculation models (LCC), (b) risk quantification techniques, (c) performance prediction and monitoring methodologies, (d) multi-criteria or cost-benefit analysis tools, (e) stress testing frameworks, (f) methods for determining technical and functional lifespan, and (g) environmental performance measurement tools, among others.

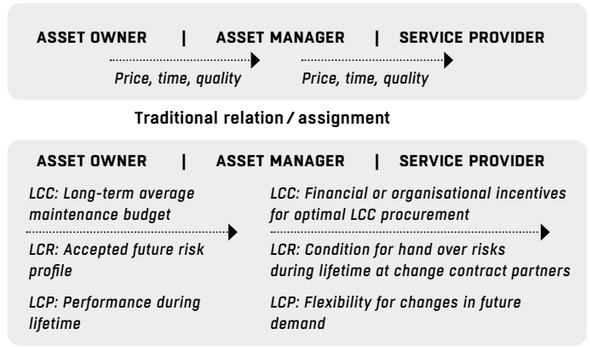
APPLICATION
LCM is applicable to asset management for civil infrastructure, buildings, and other physical assets.

LIMITATIONS
Despite the availability of various methodologies for assessing life cycle effects, the practical implementation of LCM remains challenging. The primary challenges lie in organizational culture and governance within public institutions. The true potential of LCM is realized when every decision is made with a life cycle perspective in mind. This, however, requires a fundamental shift in mindset and practice across all levels of decision-making.

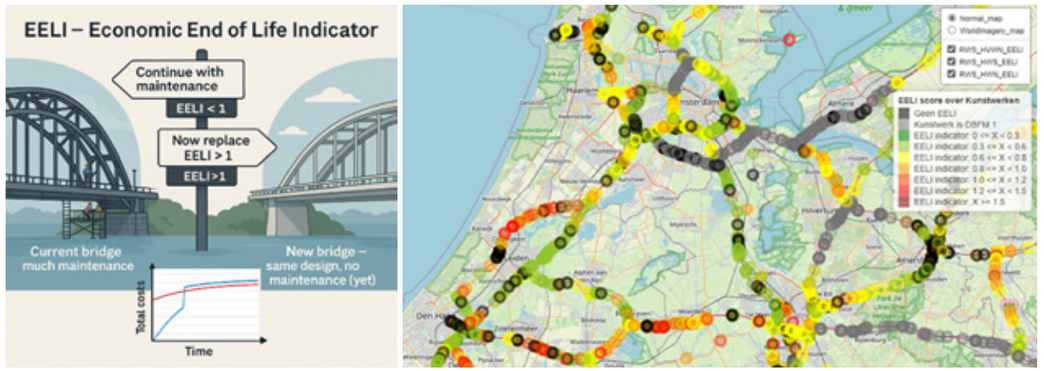
Jaap Bakker, Rijkswaterstaat

FURTHER READING: Fuchs, G.H., Bakker, J.D., & Mante, B. R. (2014). A business case of the estimated profit of life cycle management principles. *Proceedings of the 4th International Symposium on Life-Cycle Civil Engineering IALCCE 2014.* Japan ■ Van Iddekinge, R. (2020). *Linking asset management and GIS: developing a spatial decision support tool that indicates and visualizes the functional performance of viaducts and roads for replacement decisions at Rijkswaterstaat.* Master thesis. University of Twente ■ Van der Velde, J., Klatter, H.E., & Bakker, J.D. (2012). A holistic approach to asset management in the Netherlands. *Structure and infrastructure engineering 9,* 340-348. Taylor & Francis.

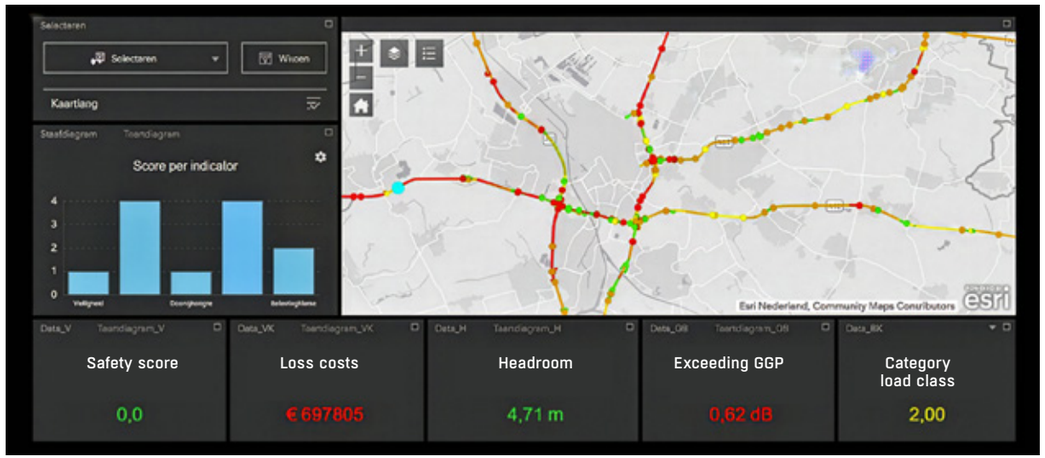




Left: Figure 1. Life cycle management (LCM) involves managing life cycle costs (LCC), life cycle risks (LCR), and life cycle performance (LCP) in a dynamic environment (Fuchs et al., 2014). **/ Right: Figure 2. LCM add-on to traditional decision-making and assignments.** [Source: Rijkswaterstaat]



The economic end of life indicator (EELI) shows the ratio between the present value of the cost of repair until the theoretical replacement year and replacing now. / The EELI can be calculated on the fly based on existing maintenance plans, and is shown on a GIS map (experimental data) to support LCM decision-making on replacement or repair. [© Rijkswaterstaat]



Functional performance map with network indicators for traffic safety, traffic delay cost, maximum vehicle height, noise pollution and load class for individual viaducts (van Iddekinge, 2022).

Plan Review

Decision makers often struggle to foresee the spatial qualities of urban investment plans. Plan review facilitates systematic and transparent discussions on this issue. How to help stakeholders to identify the most important spatial opportunities and pitfalls of urban projects?

PURPOSE – The purpose of plan review is to identify the 'soft urban values' in a plan. It is designed to complement the social cost-benefit analysis (SCBA) for public urban investments (Figure 1). It turns away from the dominant economic logic of a cost-benefit analysis and puts the knowledge developed by spatial disciplines – like geography, urban planning, and urban design – at centre stage. Unlike the SCBA, the method is not a mandatory component of public plan evaluation. The Netherlands Environmental Assessment Agency (PBL) has adapted the method also for exploratory use, focusing on urban plans near mobility nodes.

The method aims to improve communication about urban projects. It provides insight into the specific plan environment (contextuality) while offering a universally applicable system analysis (scope and repeatability). It uses clear considerations that can be understood by diverse stakeholders across disciplinary boundaries (communication), and it assesses the congruence and consistency of plans at different scales. The method helps to capture capital gains, and it provides insight into potential divestments. It involves a matrix that serves as a checklist to guide a structured dialogue – systematising and objectifying the spatial analysis of a project (Table 1). The method draws on knowledge and expertise from various spatial disciplines, like geography, urban design, and urban sociology. It includes disciplinary, tacit, and user-related information.

APPROACH – The review process is divided into three phases:

1. *Preparatory phase*: relevant spatial information about the project site is collected from various disciplines and at different scales as indicated in the matrix.
2. *Interactive phase*: a broad group of stakeholders and interested parties will prioritise this information in a group discussion. They will identify the most relevant cells and relationships between cells in the matrix. The most important spatial opportunities and risks for achieving policy or sustainability goals are then identified within this selection.
3. *Reporting stage*: potential-related values and spatial conditions are identified, reported, and incorporated in the plan. This phase highlights synergies and trade-offs between different scales corresponding levels of government and spatial perspectives from various disciplines and corresponding sectors.

Like Bijlsma, Netherlands Environmental Assessment Agency (PBL)

APPLICATION
As plan evaluation, plan review formulates an 'expert judgement' by a diverse group of experts. As plan exploration, it aims to expand the range of public values achieved by a plan. This involves experts as well as a broad group of stakeholders related to the plan or location. The method is most effective in the early stages of policy cycles and urban planning processes (Table 2).

LIMITATIONS
To be effective, the quality of the information must meet certain requirements. Specific spatial knowledge and expertise are necessary, as well as contextual information on urban uses and the existing qualities of the living environment. As the method incorporates non-monetised values, it does not always directly align with operational processes.

FURTHER READING ■ Bijlsma, L., Van Amsterdam, H., Dammers, E., & Harbers, A. (2023). *Kansen rondom spoorknooppunten. Publieke meerwaarde in gebiedsontwikkeling.* Planbureau voor de Leefomgeving (PBL) ■ Bijlsma, L., & Hamers, D. (2022). Het beste voor de stad: Planobjectivering maakt zachte waarden bespreekbaar. In De Boer, H., Hendriks, M., Hooimeijer, F., Kuijper, J., Debrock, S., Duflos, M., Dillon Peynado, T., & Schuur, G. (eds.), *Ontwerpen vanuit de doorsnede. De ondergrond als bouwsteen voor een toekomstbestendige stad,* 188-194. Public Space ■ Hamers, D., Bijlsma, L., & Van Hoorn, A. (2015). The Plan Review: A new approach to discussing, assessing and improving urban projects in a changing planning practice. In: Hull, A., Alexander, E., Woltjer, J., & Ruth, M. (eds.), *Place-based evaluation for integrated land-use management,* 261-283. Routledge.

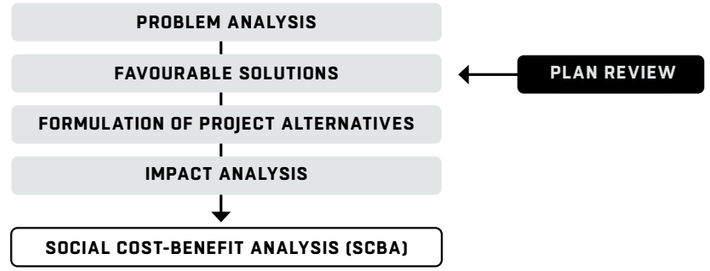


Figure 1. Position of plan review in the SCBA process: the outcome can be used to refine the problem analysis, formulate the null alternative, and substantiate the policy alternatives in the SCBA process. [Source: PBL]

	Generic/Space		Specific/Place
Daily urban system	• node value • diversity of urban environments (milieus)	• regional flow • consumption and production landscapes	• cultural landscape
Surrounding area	• types of facilities and social interaction	• urban acces • urban green structure	• barrier effect • urban icons • cityscape
Project area	• place value • urban environment	• place maker	• local spatial quality • historic buildings

Table 1. Plan review matrix: the interactive discussion involves a matrix that serves as a checklist to guide a structured dialogue, systematising and objectifying the spatial analysis of a project. [Source: PBL]

The rows of the matrix distinguish between the various relevant scales interacting with urban projects, ranging from the regional level and its 'daily urban system' to the project itself. These scales are analysed based on the spatial qualities that a project could contribute to.

The columns distinguish the types of information and knowledge required for spatial analysis. These relate to various spatial aspects that can be quantitative and abstract, as well as qualitative and concrete.

Plan exploration	Plan evaluation
Main objective is *to broaden the scope*	Main objective is *to evaluate*
Sustainability goals get priority	*Policy goals* get priority
Participants: *broad group of stakeholders*	Participants: *small group of experts*
Sketch variants, global program and *phasing* as input	*Design variants, specific program* and *phasing* as input
Identifies spatial conditions and *dependencies*	*Scores* spatial conditions, *evaluates plan consistency*

Table 2. Application of plan review. [Source: PBL]

Procurement of Infrastructure

Rijkswaterstaat, as public authority, awards contracts to the private sector for infrastructure projects and services worth around four billion euros in total yearly. Collaboration is therefore essential to fulfill public tasks. How can this collaboration be realised in the best possible way?

PURPOSE – Rijkswaterstaat is part of the Dutch ministry of Infrastructure and Water Management and responsible for the design, construction, management and maintenance of the Netherlands' primary transport and water infrastructure facilities. Rijkswaterstaat is obliged to follow European tender regulations based on principles such as fairness, transparency, and open to competition (equitable and non-discriminatory). Procurement is a strategic instrument for spending public money in an efficient and sustainable manner. Additional to purchasing value for money with a product, service, or work (e.g., a new bridge), strategic priorities based on government policies such as safety, sustainability, digitalization, and innovation need to be laid down in contractual arrangements. Some requirements and administrative conditions are standard (UAV-GC, Arvodi, ARBIT) some are organization-specific (contract models, guidelines, and requirements).

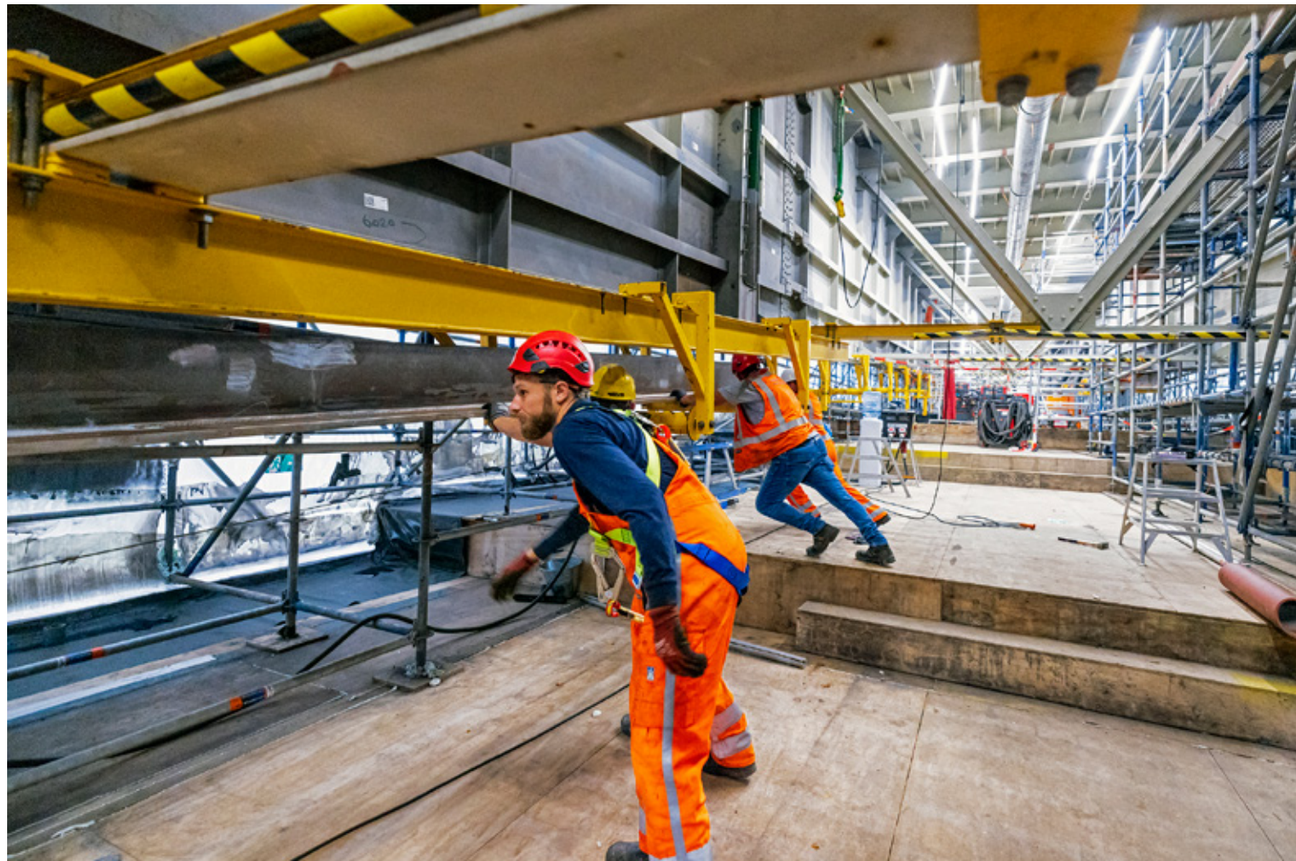
The approach, with early contractor involvement in the design phase, is gradually transitioning into a more collaborative phased approach. When the scope is clear and the risk profile is known, a lump sum engineering & construct (E&C) or design & construct (D&C) contract (UAV GC2025) is still the standard. E&C contracts are used when detailed engineering is required. However, the larger life cycle-based design, build, finance and maintain (DBFM) contracts are less used nowadays, because it is hard to allocate the risks and to agree upon a fair price. So, there is a transition from transactional contracts – with a clear scope, agreed plan of approach and a lump sum price (E/D&C, DBFM) – towards more relational contracts. These are characterised by a phased approach to jointly define the precise scope and plan of approach, with a fair price and risk allocation. Long-term framework contracts for similar types of work with a (more) regular deal flow for engineering firms and contractors facilitate standardization and innovation to increase efficiency and quality. A regular deal flow of multiple projects is crucial for all parties to optimize their scarce capacity (skilled workforce and equipment). The main reason for this transition is the increased uncertainty of the scope and related risks of the infrastructure to be renovated. The increased complexity of working in an operational network within limited timeslots requires fair risk allocations.
Pricing mechanisms, which cater for more intense collaboration during preparation and execution, are needed to manage limited budgets. Foreseeing the tremendous challenge of upgrading the aged infrastructure in the Netherlands, this approach is being further developed

APPLICATION
For infrastructural projects Rijkswaterstaat distinguishes various contract models depending on the type of work, constraints and risk profile. Depending on available timeslots in the road and waterway network and potential synergies, the optimal scope of work and contracting approach is determined. Next, to long-term regular maintenance contracts and lump sum D&C contracts for new objects (not part of a portfolio), framework contracts and two-phased D&C contracts (with delayed pricing after the design phase) are used to facilitate the long-term partnership with vendors.

LIMITATIONS
To create a level playing field for businesses across Europe and stimulate an internal European market, EU law sets out public procurement rules. These rules govern the way public bodies purchase goods, works and services. They are transposed into national legislation and apply to tenders whose monetary value exceeds a certain amount. For tenders of lower value, national rules apply. As indicated above, the scope and type of work and market characteristics determine the type of contract, risks and liabilities within overarching procurement strategies.



A12 IJsselbruggen near Arnhem: renovation project with a design & construct two-phase contract: design and research (phase 1) and realization (phase 2). [© Rijkswaterstaat, Paul Poels Fotografie]



jointly with vendors. Rijkswaterstaat manages and develops the three major infrastructure networks in the Netherlands: the main waterway network (3,415 km waterways and rivers, 23 lighthouses, 86 lock complexes, and 354 bridges), the main road network (3,072 km motorway, 30 tunnels, 2,931 viaducts, 38 wildlife crossing complexes, 17 aqueducts, 795 bridges), and the main water system (90,132 km² surface water, 6 storm surge barriers, 45 km dunes, 158 km dikes and dams, the Afsluitdijk and Houtribdijk).

APPROACH – What and how to contract depends on sourcing strategies: what to do in-house and what to procure externally. A good understanding of potential offerings, (new) technologies and market developments are crucial. There are three phases: 1. *Prepare the tender procedure:* decide and define scope, procurement strategy and plan, tender procedure, and contract model. Carry out all preparations: create the contract with all the needed specifications, finalise cost estimates, award-criteria and planning. 2. *Run the tender procedure:* select a vendor (or consortium of vendors) based on qualitative and price criteria and award the contract. 3. *Execute and manage the contract:* until final delivery of the project or service.

Carlita Vis, Rijkswaterstaat

FURTHER READING ■ Kennisplatform CROW. (2025). *UAV-GC 2025. Het uniform administratief kader voor geïntegreerde contracten.* Kennisplatform CROW ■ PIANOo. (2015). *Aanbestedingsreglement Werken 2012* (ARW 2012). PIANOo Expertisecentrum Aanbesteden, ministerie van Economische Zaken ■ Platform V&R. (2025). *Inkoopstrategie Vernieuwingsopgave – Achterban Platform V&R.* Taskforce Infra, Vitale infrasector ■ Rijksoverheid. (2022). *Aanbestedingswet 2012.* Wettenbank Overheid.nl ■ Rijksoverheid. (2022). *Gids Proportionaliteit* – 3e herziening. Rijksoverheid.nl ■ Vitale infrasector. (2020). *De marktvisie 2020.* Vitale infrasector.

PREPARE TENDER

1 Create procurement strategy (if new)
2 Create procurement plan (for specific project/portfolio)
3 Prepare & create tender documents

RUN TENDER

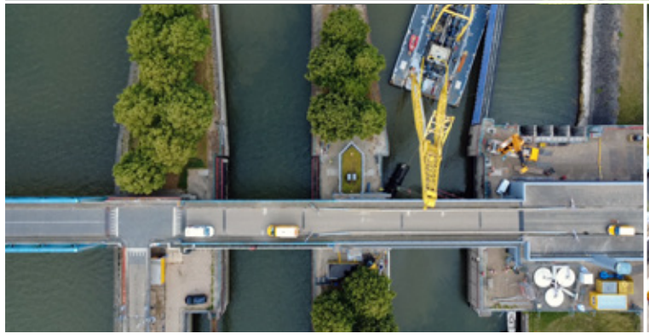
4 Run tender procedure
5 Award contract

EXECUTE CONTRACT

6 Collaborate with contractor – project delivery
7 Close contract; handover object to (internal) client
8 Evaluate

Procurement process







Prinses Marijkesluis, Rijswijk (Gelderland): the renovation project involves major upgrades to the lock gates, bridge structures and control systems, as well as concrete repairs, so the lock can continue to operate safely for the next 30 years. A floating crane lifts the 40-ton lock gate during the renovation. [© Rijkswaterstaat] **/ Oosterscheldekering in Zeeland: preservation of the gates of the storm surge barrier with an engineering & construct contract.** [© Rijkswaterstaat, Paul van Baardwijk]



Project Management for Integrated Infrastructure Design

The design and construction of large and integrated infrastructure is mostly unique, complex. It influences the social and physical environment and is surrounded by uncertainties and risks. At the same time, money and time are critical and binding factors. How to bridge such a dilemma?

PURPOSE – Project management originated from the need to coordinate large, complex engineering endeavors, such as space projects, transportation networks, bridges, etc. Since its inception, project management has evolved as a widespread approach for tackling the inherent complexity and interdisciplinarity of infrastructure projects (Bosch-Rekveldt et al., 2011). Today, it not only ensures efficiency and timely delivery, but also helps balancing competing demands from technical, spatial, environmental, and political domains. The critical potential of project management is navigating 'wicked problems' of infrastructure – characterized by ambiguous problem definitions, conflicting interests, uncertainty, long lead times, and unpredictable externalities. Here, the iterative and abductive reasoning of project management – such as testing, learning, and revising – supports adaptive, resilient responses. Effective project management contributes significantly to the integrated design and realization of infrastructure that is future-proof, resilient, and socially valuable (Hertogh & Westerveld, 2010).

APPROACH – The history of infrastructure delivery reflects fragmentation of expertise: engineering, architecture, policy, and planning operating in silos (Llancce et al., 2025). Project management emerged to provide structure and cohesion. The 'hard paradigm' emphasized SMART goals (specific, measurable, achievable, relevant, time-bound) and key performance indicators (KPIs) – using Gantt charts, critical path method, earned value analysis, etc., for control (Figure 1). This was vital for managing major infrastructure projects, where errors have lasting societal impacts, including serious financial consequences. However, as societies confronted the challenges of climate change, population growth and urban congestion, purely technical approaches fell short. The 'soft paradigm' of project management developed in response – focusing on leadership, stakeholder engagement and adaptive processes, including social and institutional contexts (Ninan et al., 2022) (Figure 2). In hard and soft paradigms, project management typically follows a phased approach (initiation, planning, execution, monitoring, closure) in which stakeholder alignment, risk management, and quality assurance are key (Figure 3).

APPLICATION
Across all types and scales of infrastructure, from localized upgrades to nationwide mobility networks. Particularly valuable in interdisciplinary and intersectoral projects involving private partnerships, environmental integration, or participatory design. Project management approaches integrating hard and soft paradigms align with the vision of integrated infrastructure design (Ninan et al., 2022).

LIMITATIONS
Over-reliance on the hard paradigm and neglecting dynamic urban and environmental context may marginalize stakeholders, suppress innovation, or delay decision-making. Conversely, an overly soft approach may risk scope creep or lack clear accountability. Balancing both paradigms is key for achieving integrated, value-driven infrastructure outcomes.

Johan Ninan & Marian Bosch-Rekveldt, TU Delft

FURTHER READING ■ Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *International Journal of Project Management, 29(6),* 728-739 ■ Hertogh, M., & Westerveld, E. (2010). *Playing with complexity. Management and organisation of large infrastructure projects.* Erasmus University Rotterdam ■ Llancce, A.O., Lim, Y., Esteban, T.A.O., Van Leeuwen, J., & Ninan, J. (2025). From silos to synergy: Conceptualizing an integrated infrastructure design for climate resilience in Rotterdam. *Climate Risk Management, 47,* 100691 ■ Ninan, J., Hertogh, M., & Liu, Y. (2022). Educating engineers of the future: T-shaped professionals for managing infrastructure projects. *Project Leadership and Society, 3,* 100071.

ID	Task Name	Predecessors	Duration
1	Start		0 days
2	a	1	4 days
3	b	1	5.33 days
4	c	2	5.17 days
5	d	2	6.33 days
6	e	3,4	5.17 days
7	f	5	4.5 days
8	g	6	5.17 days
9	Finish	7,8	0 days

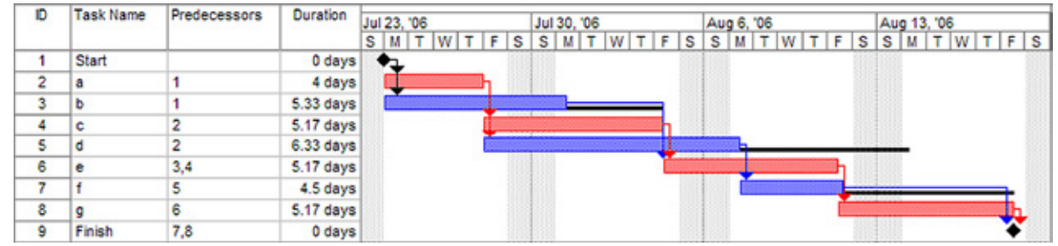


Figure 1. Hard paradigm example: Gantt chart in Microsoft Project with critical path in red, used in order to schedule project tasks and track progress. Earned value analysis can monitor budget and timeline adherence. These tools emphasize measurable control and predictability. [CC Dbsheajr]

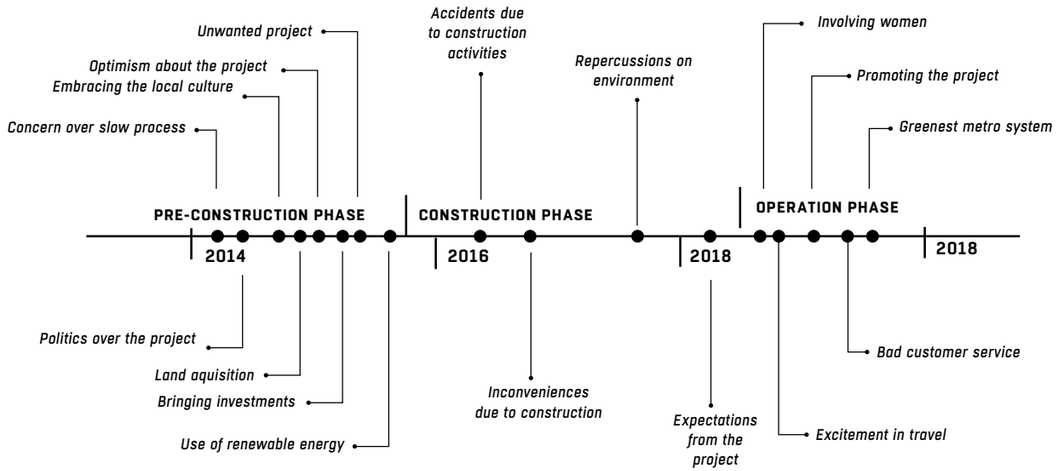


Figure 2. Soft paradigm example: different community issues during the life cycle of an infrastructure project. Community stakeholders can be engaged through workshops and public consultations. Leadership practices can encourage interdisciplinary and multi-stakeholder collaboration by working closely during the project lifecycle on diverse issues that projects can face. Flexible decision-making processes can accommodate political or social changes and help projects be resilient to changing demands of society. These approaches emphasize dialogue, learning, and adaptation. (Ninan, J., & Rupesh, Y. (2023). Megaproject and the city: Theorizing social media discourses across the life cycle of an infrastructure project. *City and Environment Interactions, Volume 20.* 100123)

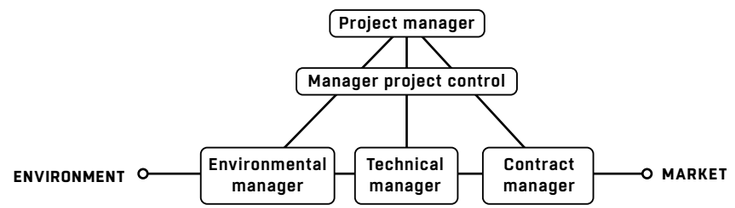


Figure 3. IPM model: integrated project management models can help understand distinct roles in an infrastructure project. [Source: Rijkswaterstaat]

Research by Design Framework

As most infrastructure in the Netherlands was realised in the 1960s and 70s, extensive maintenance and replacement is now needed. Furthermore, climate change and its effects are challenging our vital transport, water, and energy systems within the built and natural environment. This raises the question if and how infrastructure can adapt or must be replaced due to changing conditions, and if so, whether it can create new conditions for system transition and future development. These questions are surrounded by complexity, uncertainties, and unknowns. How to address these in planning and designing infrastructure in its social, economic, ecological, and cultural-historical context?

PURPOSE – Research by design is a method to investigate the spatial organization of the built and natural environment – within the domains of architecture, urban design, and landscape architecture – to increase insights, develop knowledge, identify conflicting spatial claims, and create new opportunities, – based on design as means of inquiry and communication. It can deal with vague or ill-structured issues and problems within a broad context related to a multitude of urban and natural systems and accompanying infrastructure, by exploring directions and vistas under different conditions, including the transitions these systems are facing, like climate change and the need for its mitigation and adaptation. It investigates likely and conceivable futures, which can be envisioned and visualied to get a better understanding how systems and its infrastructure could be more future-proof, like protection against sea level rise or excessive rainfall. Or: how can particular infrastructural interventions, like a railway connection or tunnel creates new conditions for regional development, urban change, and/or ecological restoration? This happens by asking 'what if' and 'how' – based on plausible assumptions and situational scenarios – and how developments, like sea level rise, demographic change, housing and mobility needs, could evolve within an extended period, and what impact one could expect that design can respond to. Not per se, as an actual solution, but to understand causal relationships and potential risks, and to reveal potential value within a broad and future context. This serves as the 'front-end' in a planning or policy process.

The method is speculative about the future, but when informed by experts and stakeholders, and supported by a plausible narrative, it can give insights and leads as a stepping stone for prospects of action and change for involved stakeholders. To be effective and efficient within a governmental and policy context, it is necessary that the actual design activities are embedded within an organizational framework that both facilitates and structures the process in a systematic and transparent way. Involved stakeholders, with their expectations and interest, should feel confident about the phasing and its execution to keep them on board so continuity to attend will be maximal. To enhance plausibility and commitment with the outcome and its significance for policy development, it is necessary that the issues and problems which will be investigated have a connection to policy agendas, that experts from different disciplines and sectors are involved, and that data is used if available. An open mindset and attitude among involved stakeholders are essential, as well as some distance to procedural processes to stimulate thinking freely, so that those involved are not hindered by defending positions or interests as organisational agents.

APPLICATION
For area development and large-scale infrastructure development or replacement. Different methods and techniques can be used within the framework for resident participation, spatial analyses, visualisation, communication, etc.

LIMITATIONS
The choice for designers should be aligned with the issues and challenges to be addressed. Professionals will bring in their own reference frame and experience which could influence the results. To be effective, stakeholders must consider a follow-up strategy for communication in their organisation and informing policy.



Figure 1. Four steps to distinguish for research by design. The duration of the individual steps is arbitrary and the necessary iterations to analyse, design, and evaluate depends on the planning and budget of the initiators, and on the availability of designers and experts for their substantive tasks. Completing a study within a year helps keep stakeholders engaged, motivated, and committed. [Hans de Boer]

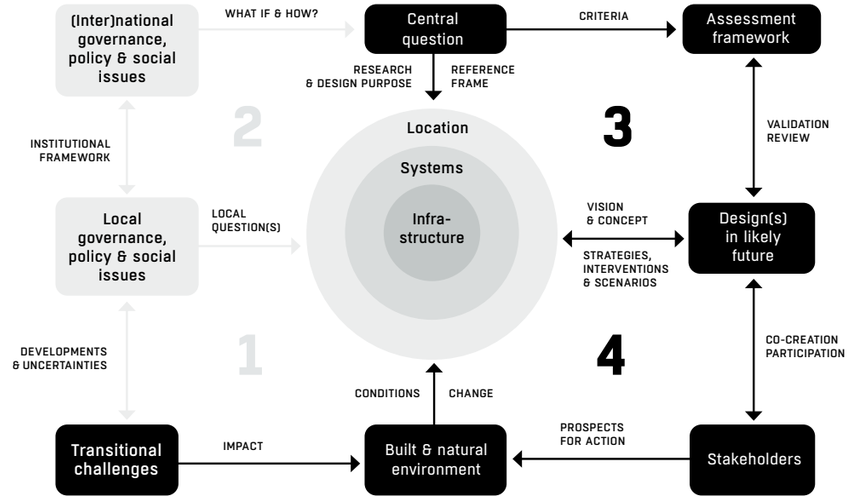


Figure 2. Overview of interrelated aspects for using research by design within a policy context. [Hans de Boer]

1. Symbolises the impact that transitional challenges like climate change or the mobility system can have on the built and natural environment. Local governance must deal with all kinds of developments and uncertainties by formulating policies for related social issues.

2. Symbolises the governmental hierarchy related to spatial planning, infrastructure, and the environment. Agreements and policies for addressing issues like climate change or environmental protection have an international dimension. The national government is the body which must deal with social and environmental issues in general and is responsible for long-term development, preservation of nature, maintenance of national infrastructure, etc. Policies and budgets at national level complement the institutional framework that the local government must consider for its policies.

3. Shows the importance of an assessment framework based on criteria derived from the central question and a palette of values like spatial quality, sustainability, resiliency, added value, and well-being. This gives designers a high degree of freedom without prescribing solutions. It makes it possible to assess strategies on their potential contributions and impacts. Situational scenarios based on driving forces at macro level can show their robustness: economy (e.g. growth/contraction, local/global), politics (e.g. market/government, autonomy/centralism), technology (e.g. digitalisation, automation), society (e.g. individualism/collectivism, conservatism/progressivism), climate change (e.g. gradual/acceleration, moderate/extreme impact). The Netherlands Environmental Assessment Agency (PBL) has conducted various exploratory spatial planning studies based on self-developed situational scenarios.

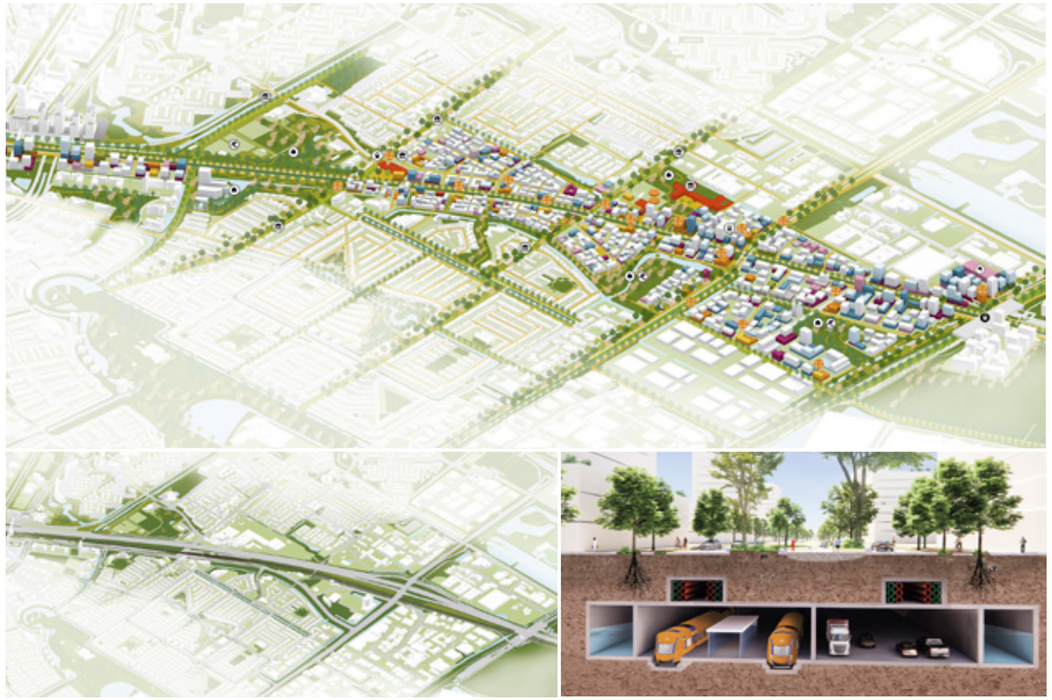
4. Emphasises the involvement of relevant stakeholders with the actual analysis and design activities by designers and experts. They have knowledge about the case area, have specific expertise, are member of an organisation, or are organised as a user or neighbourhood community. Collaboration and Interaction enhance the quality and acceptation of results.

APPROACH – The framework distinguishes four interrelated and partly cyclical steps which are based on interactive workshops; the preparation and processing of feedback are off-site tasks by designers who do the actual research and design activities (Figure 1). The organizers of the use of research by design must take responsibility for the overall process of the next steps:

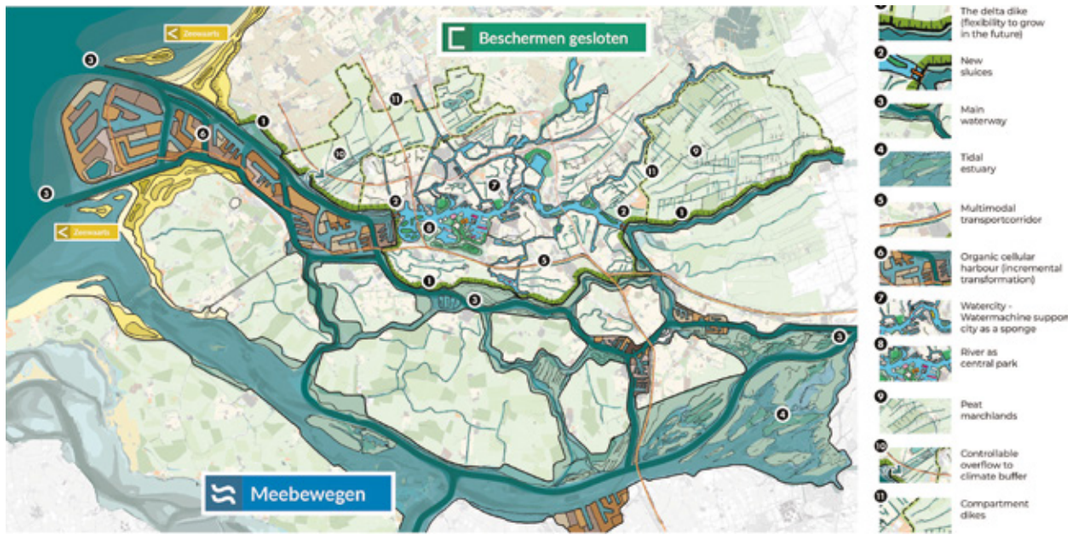
1. *Define*: formulate a central investigative and guiding question which addresses a social issue related to infrastructure and which expresses commonly shared values within its present and future social, economic, ecological, and cultural-historical context (Figure 2). E.g.: How to reduce the barrier and environmental impact of a busy motorway in a dense urban area so that an attractive, healthy, and future-proof living environment could be created, while generating sufficient social, economic, and ecological value to justify investments for necessary infrastructural interventions? Such an overarching and generic question which reflects national and local interests and stakeholders. Local questions are more specific for a particular area (e.g. modal shift, blue and green structures, soil and subsurface) and circumstances (e.g. socio-economically disadvantaged residents, social safety). The central question could cover various locations as individual cases, so a comparison is possible at a large scale and higher system level. Both types of questions feed the research and design purpose, and are related to criteria which are relevant to consider social, economic, ecological, cultural-historical values from a sustainability and resiliency point of view ('broad prosperity'). Recording all these matters in a reference document provides guidance for the further process.
2. *Analyse*: ahead of the actual analysis by the performing designers and other experts, master classes can bring in actual and specific knowledge which is relevant for the case(s). Expert sessions can deepen the case(s) for understanding the involved systems and infrastructure. Fact-finding and discussion with local, regional, and national stakeholders is crucial to encourage mutual understanding and to develop a shared reference frame.
3. *Design & evaluate*: the conclusions from the analysis must be translated into a vision for the location(s) and a basic concept and principles by the performing designers. The interaction with stakeholders in design workshops is also a test of how far they recognise its potential. Proposed alternative strategies and interventions can be co-created and discussed in an interactive manner. Situational scenarios, which represent possible future conditions, can be used as testing ground. Such scenarios can reveal the robustness of the strategies and interventions discussed. Furthermore the potential positive effects and benefits of the alternatives can be discussed and validated and reviewed against the criteria to prioritise a preferent strategy and intervention. The value of positive effects and benefits can be determined by economists who work closely with the designers.
4. *Finalise*: the preferent strategy and intervention(s) will be elaborated; sketch designs or renders and future images projected in a likely and conceivable future embody the narrative. This approach, with feet on the ground and heads in the clouds, is necessary to present both the narrative's plausibility and its potential for change. Organizers must take care to document the process and results. Research by design is about insights and leads for the issues that stakeholders must deal with. They must set further steps within their organizations to communicate the results and inform plans and policies which define prospects for action and change within the built or natural environment, considering the values related to broad prosperity.

Hans de Boer, TU Delft

FURTHER READING ■ Berlingieri, F., Cavallo, R., Corradi, E, & De Boer, H. (eds). (2022). *Design actions for shifting conditions.* TU Delft Open Books ■ De Boer, H., Duinmayer, M., Gerretsen, P. Hinterleitner, J., Van der Wall, R., & Zonneveld, J. (eds). (2025). *Afslag meerwaarde. Tekenen en rekenen aan brede welvaart in stedelijke snelwegzones.* Kennis- en Innovatieplatform Stedelijke Snelwegen & Ruimtelijke ontwikkeling (SSRO) ■ De Urbanisten, LOLA (LOst LAndscapes), & Royal Haskoning DHV. (2024). *Rotterdam, from a port city to a port archipelago + sponge watercity.* Report Redesigning Deltas study. Delta Urbanism Interdisciplinary Research Programme, TU Delft.



Zoetermeer, A12 motorway: design proposal by Venhoeven CS for tunnelling the motorway and railway for 4 km, which creates 1km² additional space to accommodate approx. 15,000 homes, 650,000 m² of commercial surface, 300,000 m² amenities, and 350,000 m² of greenery; and eliminates negative effects and improves the existing living environment (De Boer et al., 2025). [© Venhoeven CS]



Rotterdam in 2200: vision by De Urbanisten et al. (2022) for the port and city in case of a sea level rise between 1 and 3 metres in 2100. The port will be fully accessible, but the city – as a Sponge City – will be closed off from the Nieuwe Maas River by sluices and delta dikes. The vision, as one of the cases in the Redesigning Deltas design study, incorporates the 'move along' and 'full closure' adaptation strategies to sea level rise as defined by Deltares. [© De Urbanisten]

Stakeholder Analysis

'Not in my backyard' (NIMBY) is a euphemism for serious resistance to a project. In case of infrastructure, it can lead to severe delays and high additional costs. How can we get timely insight in the position and concerns of actors who must deal with the consequences or have a stake in the project?

PURPOSE – Stakeholder analysis in integrated infrastructure projects is an essential methodology for providing insight into the complexity of these projects, the challenges encountered, the interests, concerns, and priorities of the involved parties, and the possible consequences that policy interventions or project initiatives have for different groups or individuals. Stakeholders or interested parties can be defined as 'any group of people, organised or unorganised, who share a common interest or stake in a particular issue or system', according to Grimble & Wellard (1997). Stakeholder analysis can help identify stakeholders based on their attribution, interrelationship and interests related to a given issue or resources. They identified two key impacts of stakeholder analysis in practical terms: one is to enhance the selection, efficiency, effectiveness, and evaluation of policies and projects; and the other is to improve the assessment of the distri-butional, social, and political impacts of projects. Stakeholder analysis helps recognise whose interests should be considered when deciding and why these stakeholders' perceptions should be considered when determining policy, implementing urban interventions, and realising spatial, economic, and social outcomes.

APPROACH – Stakeholders can be identified at any scale of the society, from the global and national to the local, the household, and even within the household itself. More specifically:

1. Parties who are actively involved in the problem or are linked to the affected geographic scale or the project location.
2. Parties who affect a decision, e.g. related policy or regulation authorities, or those responsible for investment, financing, execution, operation, and maintenance.
3. Parties who have the knowledge, insights and ideas that contribute to the problem solution.
4. Parties that are affected by the decision or action, e.g. local community or a broader group that influences public perception (Koppenjan & Klijn, 2004; Grimble & Wellard, 1997).

The practical methods for stakeholder analysis include policy documents and project reports, spatial mapping, interviews, snowball sampling, surveys, workshops, focus groups, social network analysis (SNA), stakeholder circle methodology, and a power/interest matrix. Table 1 shows a roadmap to implement a stakeholder analysis.

APPLICATION
Stakeholder analysis can be applied in the field of policy, management, and project development. Through stakeholder analysis, the interest and perspective of involved parties, as well as their influence on the project becomes explicit. Useful in problem-solving and impact assessment.

LIMITATIONS
The political and economic context, policy environment, the project context or the interest and standpoints of involved parties can shift over time. Especially if the project is situated in a complex and unstable setting, the stakeholder analysis can become less relevant and need an update.

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FURTHER READING: Grimble, R., & Wellard, K. (1997). Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences, and opportunities. *Agricultural systems, 55*(2), 173-193 ■ Koppenjan, J. F. M., & Klijn, E. H. (2004). *Managing uncertainties in networks: a network approach to problem solving and decision making.* Psychology Press.

Windmills in Eemshaven, Groningen. [CC Bayke de Vries]

1 Define a tentative problem formulation and analytic framework, with the aim to define a problem situation or initiative, as the base for the stakeholder analysis.
- What is the general context and current situation of the problem?
- What is regarded as the cause of the situation?
- From which perspective is the problem addressed?
- What can be the (undesired) consequences that derive from the current situation?
- What is the desired situation or vision?
- What assessment criteria are used to evaluate the problem?
- What are the policy context and existing planning documents?
- What investment mechanism is pursued?

2 Identify relevant stakeholders from the perspective of the problem and analytic framework.
- Which stakeholders are actively involved in the problem?
- Which stakeholders have the power to hinder or stimulate the process? Who has authority or other resources that play a role in the emergence or solution of the problem?
- Which stakeholders have an interest in finding a solution to the problem?
- Which stakeholders have knowledge, insight and ideas that can contribute to the enrichment of the problem formulation or solution?
- Which stakeholders get involved or are expected to become involved at a particular moment?
- Which actors are not likely to participate, but are affected in some way by the problem or the approach to it?

3 Inventory stakeholders' problem perceptions concerning the cause of the problem and its possible solutions.
- What standard do stakeholders use to assess the situation?
- What do stakeholders perceive about problems, causes, solutions and competency of involved parties?
- What are the most important causes of the problem situation in their view?
- To what extent do the perceptions differ, and are there clear favourites among the various solutions?
- What obstacles or conflicts could be caused by differences in perception?
- What means of influence do they distinguish regarding the problem situation and its causes?

4 Analyse the positions of stakeholders and their response based on the type of resources and the degree of dependence. This provides an overview of possible responses from involved stakeholders to a specific problem formulation and the consequent solution direction.
- Which stakeholders have what resources to influence the process?
- What means do different stakeholders have at their disposal?
- How significant are the means and can they be acquired elsewhere?
- Is there unilateral or mutual dependency?
- Are stakeholders critical, dedicated and/or similar?
- What are the similarities and differences between problem perceptions, interests, and objectives of stakeholders and to what extent does that lead to potential support for and resistance against the potential solution?

Table 1. Roadmap to implement a stakeholder analysis (Koppenjan & Klijn, 2004).

Transit-Oriented Development

The rise of the car, as an individual means of transport, has led to urban sprawl, separation of urban functions and ultimately to polycentric urban regions. However, this is undesirable because it increases the distances between urban functions, thereby promoting car dependency and reducing the conditions for cycling and public transport. However, the effects can be mitigated by a smart urbanisation strategy.

PURPOSE – Transit-oriented development (TOD) is a spatial planning concept that aligns mobility and land use, particularly by linking suburban areas to public transport. Public transport serves as the backbone, with spatial development concentrated around the nodes. Planning, financing, and operation are addressed in an integrated way. Urban sprawl results in car dependence, but clustering urbanisation at higher densities and mixing functions can reduce travel distances while strengthening support for public transport. In the Netherlands, this insight led to the concept of the *urban region* and later to the *compact city* strategy. The resulting neighbourhoods are referred to as VINEX locations, named after the national spatial planning policy of 1991. Over time, however, polycentric urban conglomerates gradually emerged, as expanding cities physically converged and became functionally interconnected. This has led to increasingly diffuse mobility patterns. Since such network cities are not easily served by public transport, an urban development strategy aimed at public transport nodes has been conceived. This is referred to as transit-oriented development, a term coined in the US by Peter Calthorpe (1993). While in the US the term TOD refers to development around rail stops connecting suburbs to downtown like in Portland (Van Lierop et al., 2017), in the Netherlands the emphasis is mainly on regional networks (Staricco & Brovarone, 2018), like the RandstadRail and recently the conversion of the Hoekse Lijn into a light-rail connection, aiming at urban development around stops.

APPROACH – TOD aims to provide housing, amenities, and workplaces with high-quality public transport. According to Bertolini's (1996) node-place model, both aspects should be balanced. High urban density around the stops is necessary to attract enough passengers. In the US, development mainly takes place within walking distance (often 400 metres). In the Netherlands, bicycles provide a larger catchment area around the station (approximately 3 kilometres). On the destination side, walking distance must be maintained for amenities and employment, located as close as possible to the station. Shared bicycles and additional urban public transport can bridge the 'last mile'. The networks of which the hubs are part are often based on the train, but can also consist of light rail or high-quality bus connections; a hub preferably connects multiple modes of transport. TOD implies mixing homes, work, and amenities, which enhances spatial synergy and prevents one-sided transport flows.

APPLICATION
TOD is generally applied in dispersed urban regions with multiple cores. It requires integrated area development in which the government actively takes the lead, market parties and citizens are involved, and cooperation must be organised between all stakeholders (Van Lierop et al., 2017).

LIMITATIONS
TOD is complicated due to spatial, financial, and governance barriers and the diversity of actors. Preferably, higher property revenues are needed to cover costs of node development.

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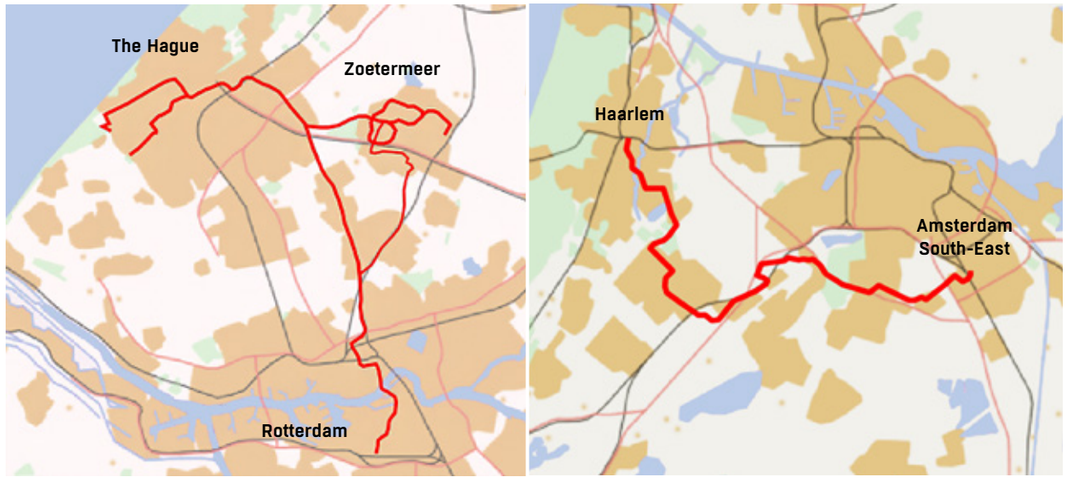
FURTHER READING ■ Bertolini, L. (1996). Nodes and places: complexities of railway station redevelopment. *European Planning Studies, 4,* 331 – 346 ■ Bleijenberg, A. (2017). *New mobility. Beyond the car era.* Eburon Academic Publishers ■ Calthorpe, P. (1993). *The next American metropolis: Ecololgy, community, and the American dream.* Princeton Architectural Press ■ Staricco, L., & Brovarone, E.V. (2018). Promoting TOD through regional planning. A comparative analysis of two European approaches. *Journal of Transport Geography 66,* 45–52 ■ Van Lierop, D., Maat, K., & El-Geneidy, A. (2017). Talking TOD: learning about transit-oriented development in the United States, Canada, and the Netherlands. *Journal of Urbanism, 10(1),* 49-62.



Monocentric urbanisation (left) has increasingly expanded into polycentric urban regions (right). To avoid low-density suburban expansions becoming car-dependent, rail lines must connect suburban stops. Urban development is concentrated at these nodes with greater densities and a functional mix, while the environment is simultaneously enhanced for walking and cycling. [© Arie Bleijenberg]



Left top and bottom: RandstadRail, South Holland is the result of policies of local and regional authorities and public transport operators. Light rail in Beatrixkwartier, The Hague. [CC A4-Nieuws / CC Michiel1972] **/ Right top and bottom: Zuidtangent, Amsterdam metropolitan region: a bus rapid transit connection combining existing infrastructure and a free track. Bus stop at railway station Hoofddorp.** [PD Willem_90 / PD Michiel1972]



ANALYSE

TURN UNKNOWNS INTO KNOWNS AND EXPLORE OPPORTUNITIES



Hondsbossche Zeewering, Petten, North Holland: reinforcement of the sea dike, with dunes as natural flood defence measure and a beach for recreation.
[© Aerophoto Schiphol]

A COMPARATIVE STUDY

SOCIETAL BENEFITS OF MULTIFUNCTIONAL DESIGN

In general, multifunctional design is hailed as the way to go for combining various purposes and activities in one project to reduce costs or to create added value. However, practice can be more complicated than one would wish for. With the realisation of several projects, we can look at their promises and outcomes. What are favourite factors when taking this approach and when it is better to take a more step-by-step and singular approach?

Spatial designers – such as landscape architects and urban designers – and civil engineers can enlarge the societal benefits of their designs by adding extra functions, like a bicycle road to a dike, a toad pond to a river expansion, or solar energy production to a highway. This is mostly practical if such additions have relatively small costs compared to the total cost of the infrastructure, i.e. the dike, river expansion or highway. This seems a smart way to generate more societal impact. *But are multifunctional designs truly more beneficial to society than monofunctional ones in practice?* This is investigated by comparing the cost-benefit balances of ten multifunctional flood protection projects with their monofunctional counterparts within the Dutch water system. This initiative originated from the Dutch Parliament, which aimed to explore whether a multi-purpose approach – combining flood protection with spatial quality – would yield greater societal benefits than a single-purpose approach with flood protection only.

This contribution focuses on *multifunctional design*, one of the seven sustainable design principles developed by consultancy and engineering firm Witteveen+Bos. Together, these seven principles form a way to make infrastructure designs within the natural and built environment less costly to society and/or to make them generate more benefits for society. The other design principles, among which circular design and participatory design, are described separately in this design guide. [Benefit-Oriented Design, page 276]

Setting up a basis for determining costs and benefits of multifunctional design

To figure out whether multifunctional designs are more beneficial to society than monofunctional ones, an analytical cost-benefit framework must be set up, in which design modes can be compared in terms of societal costs and benefits.

Distinguishing three design modes – To address the central question, it is not sufficient to just compare 'safety-only' designs with integrated multi-purpose designs. In practice, it is quite common to serve different societal goals by multiple single-purpose designs. Therefore, three design modes need to be compared:

1. *Safety-only design*: this only includes technical safety measures, such as dike strengthening, while other societal purposes are not served.
2. *Multiple single-purpose designs*: this means that there is a safety-only design and there are separate designs to serve purposes other than flood protection, such as nature, recreation, transport, cultural heritage, agriculture, energy, housing, etcetera.
3. *Integrated multi-purpose design*: in which both flood protection and other purposes are served at the same time by a combination of technical and/or nature-based safety measures and/or other so called 'add-on' projects in the fields of nature, recreation, transport and so on, that can be combined with safety measures.

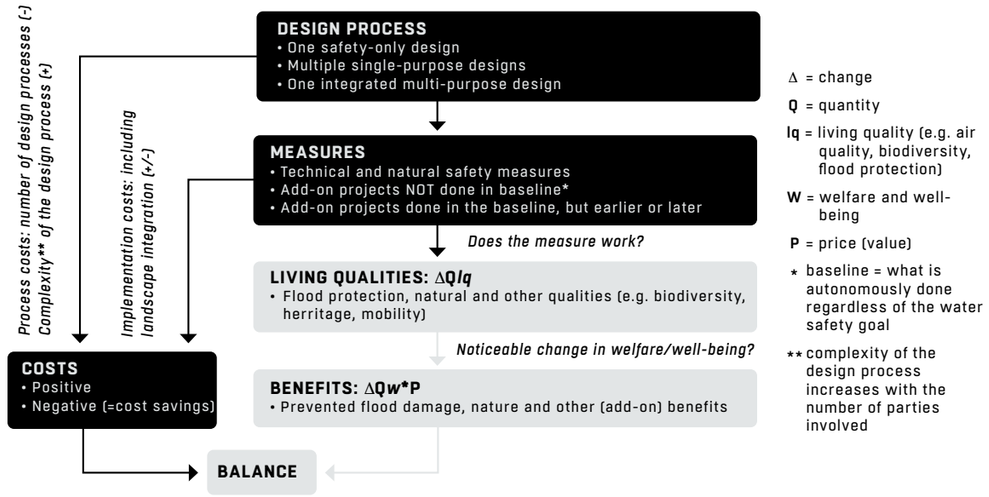


Figure 1. Analytical cost-benefit framework for positioning and assessing the three design modes. [© Elisabeth Ruijgrok]

It may be noted here that landscape integration is a standard component of every technical safety-only design. It is not an additional measure that turns a safety-only design into an integrated multi-purpose design, since landscape integration is a precondition to obtaining the licenses needed to implement a flood protection project.

Comparing the design modes in terms of societal costs and benefits

The three design modes have different costs and benefits. The analytical framework of the socio-economic cost-benefit analysis aids to identify the key differences between the three modes (Figure 1).

Differences in process costs – Figure 1 shows that the three design modes, one safety-only design, multiple single-purpose designs and one integrated multi-purpose design, differ in terms of process cost. One safety-only design is expected to have the lowest process cost, as there is only one relatively simple design process with only water management parties involved. Multiple single-purpose designs means that there as many design processes as there are purposes served, but these are individually simple, involving only the relevant parties for each purpose, such as nature managers for nature purposes or heritage conservationists for cultural heritage purposes. With one integrated multiple-purpose design there is only one design process, but this is complex because many different parties, such as water managers, nature managers, heritage conservationists, energy developers, etcetera, are involved and they all need to cooperate. Though one safety-only design has the lowest process cost, one cannot tell in advance whether one integrated multi-purpose design has lower or higher cost than the sum of the costs of several single-purpose designs.

Differences in implementation costs – Figure 1 makes clear that the three design modes entail different measures with different implementation costs. Since the safety-only design comprises technical flood protection measures only, it has the lowest implementation costs. The implementation costs of both multiple single-purpose designs and one integrated multi-purpose design depend on what would happen autonomously regardless of the flood protection project, i.e. in the baseline: would the natural safety measures be taken then? Would the add-on projects, such as recreation, heritage, energy, or shipping measures be carried out then? And if so, would that be at the same moment, or earlier or later than when integrated into the flood protection project?

Measures that are autonomously taken, i.e. that those are also done in the baseline, do not lead to extra implementation cost for an integrated multi-purpose design unless the integration of measures into the flood protection project is brought forward in time. The present value of a cost becomes higher when costs are brought forward. This automatically also means that there will be cost savings if measures are pushed backwards in time by the flood protection project. For the comparison of the three design modes these costs and benefits are actually irrelevant, because these are always there, regardless of the flood protection project.

Though the baseline determines the implementation costs, there is one other determining factor, which is often called ‘making work with work’. This means that either the technical safety measure becomes cheaper through a natural safety measure or an add-on project, or the other way around. For example, dike strengthening becomes cheaper thanks to cheap clay from a nearby nature development (e.g. from digging a side gully or lowering a riverbed) or from dredging out a shipping route, as an add-on project. This all means that one cannot tell in advance which has the lowest implementation costs: multiple single-purpose designs or an integrated multi-purpose design. It is, however, clear that one safety-only design is the cheapest of all, making it an enticing choice for budget constrained water managers.

Differences in benefits of improved living qualities – A safety-only design may have the lowest process and implementation costs, but it only improves flood protection and no other living qualities. Natural solutions and add-on projects do improve various other living qualities, such as biodiversity, recreational attractivity, cultural heritage, energy availability, mobility and so forth. This means that safety-only designs have the lowest socio-economic benefits. Multiple single-purpose designs or one integrated multi-purpose design have more benefits, namely the additional benefits of natural solutions and add-on projects.

Determinants of the balance – Whether a safety-only design has a positive balance or not simply depends on the magnitude of its flood protection benefits compared to the process plus implementation costs of the technical safety measure, including its legally required landscape integration. Whether an integrated multi-purpose design has a more positive balance than a safety-only design depends on the individual balances of the added natural solutions and add-on projects. Though it makes sense to only add natural solutions and add-on projects that individually have a positive balance, it could be also rewarding to add ones that do not, if the additions reduce the total implementation costs significantly.

Ten multifunctional flood protection cases within the Dutch water system

To investigate whether integrated multi-purpose designs have a more positive balance than safety-only designs and/or multiple single-purpose designs, ten flood protection cases were selected from the Dutch national High Water Protection Programme, the Room for the River Programme and the Weak Coastal Links Programme (Table 1). The selection criteria were:

- At least one natural safety solution or one add-on project was added to the flood protection project. Projects with only landscape integration were not selected since landscape integration is not a discriminating factor, as it is a standard component of both mono- and multifunctional designs.
- There was variation in the type of add-on projects (e.g. nature, heritage, shipping, or energy projects).
- Preferably a social cost-benefit analysis (SCBA), or else a cost effectivity analysis or environmental impact analysis, was carried out for the project, so that there is economic information available



Figures 2–3. Well-Aijen Zuid, Limburg: high water discharge canal shown with the regular water level. [© Rijkswaterstaat, Joop van Houdt] **/ Discharge of high water via the discharge canal, February 2020.** [© Rijkswaterstaat, Studio Retouched]



	Case	Planning period*	Governmental programme	SCBA, CEA or EIA** available	Considered add-on projects
1	**Meandering River Maas (Ravestein Lith)**	2016 – 2022	High Water Protection	SCBA (national & regional scale)	recreation, shipping, agriculture, and nature
2	**Green River Well**	2016 – 2022	High Water Protection	Decision document with costs; EIA	nature (brook restoration), agriculture, and heritage
3	**Dike Strengthening Tiel-Waardenburg & River Expansion Varik Heesselt**	2014 – 2018	High Water Protection	SCBA (national scale)	nature, water quality, housing, recreation, and heritage (castle)
4	**River Climatic Park IJsselpoort**	2006 – 2022	High Water Protection	SCBA (regional scale)	recreation, heritage, nature, water quality, industry, shipping, and energy (solar)
5	**Overtopping Resistant Dike Hoorn-Edam**	2010 – 2015	High Water Protection	SCBA (regional scale)	nature, recreation (day & overnight), and heritage
6	**Redevelopment of Boulevard Scheveningen**	2006- 2015	Weak Coastal Links	SCBA (national & regional scale)	redeveloping public space boulevard, and parking lots
7	**Strengthening Hondsbossche and Pettemer Sea Defence**	2004 – 2013	Weak Coastal Links	SCBA (regional scale)	recreation and nature
8	**Dike Moving Lent**	2007 – 2016	Room for the River	SCBA (regional scale)	housing, recreation, and nature
9	**Area Development Ooijen-Wanssum**	2007 – 2012	Room for the River	quick scan SCBA (and business case)	mobility, housing, and nature
10	**Strengthening IJsselmeer dike and Lelystad Kethel bridge**	2020 – 2022	High Water Protection	EIA with cost estimate	two kinds: natural solution (rendering dike heightening unnecessary) & pure add-on projects (nature, mobility, industry, harbour, recreation, and energy)

Table 1. Overview of the selected case study projects and their characteristics. *From start to final design. **SCBA = social cost-benefit analysis, CEA = cost effectivity analysis, EIA = environmental impact assessment.

to analyse. A SCBA is mandatory for Dutch governmental infrastructure projects. [Social Cost-Benefit Analysis, page 200]

- Only projects that have been completed or for which the final design has been decided upon were selected. For those projects we can determine what natural solutions or add-on projects have been carried out or selected.
- Only recent projects were selected. Projects carried out long ago were not selected, because their project leaders may no longer be approachable for information (e.g. retired, job change).

All selected case study projects were intended as integrated multi-purpose flood protection projects, for which several designs were made. All projects had a safety-only design and one or more other designs. By comparing all these designs, the contents of the three design modes (safety-only, multiple single-purpose and integrated multi-purpose) were distilled.

Main characteristics – Table 1 shows that the selection consists of six High Water Protection Programme projects, two Room for the River projects and two Weak Coastal Links projects. For most projects, a SCBA was available. When a SCBA is available, usually there is also an environmental impact assessment available, but not the other way around. These studies were carried out by different consultants and commissioned by provinces, water boards and/or municipalities. Though the flood protection projects served national flood protection goals, the spatial scale of the cost-benefit analyses was mostly regional. This scale was chosen, because the add-on projects were mostly suggested by regional parties and it is assumed that these projects are at least partly paid for by regional (public) parties and not by the national government (as is the flood protection project). Regional decision makers would like to know what an integrated multi-purpose design means for their region in terms of costs and benefits.

The case study selection encompasses a broad selection of add-on projects in the fields of nature, recreation, cultural heritage, housing, industry, agriculture, land and water mobility, water quality, public space improvement, and energy. All selected High Water Protection Programme projects and Room for the River projects include natural safety solutions.

Table 1 reveals that the planning period of the case study projects varies significantly: most projects have a period of five to nine years, but they can take up to fifteen years. This was the case for (4) River Climatic Park IJsselpoort – counted from the very first initiative by a nature conservation party and the Forestry Commission – and (9) Area Development Ooijen-Wanssum. It may be noted here that exact starting points cannot be determined in an unambiguous manner for all projects. This does not negate the fact that large differences in the duration of the planning and design process can be discerned. This is a first indication that process costs may vary significantly for flood protection projects.

Data collection: Questions to be answered – For each case, the following information was gathered based on a series of questions and entered into a database:

- What were the reasons for suggesting a natural solution or a add-on project, e.g.: implementation cost reductions; making use of the 'buzz' of the safety-only design process in the region; reducing the nuisance of digging up an area multiple times; obtaining a visually more beautiful design; and/or enabling economic activities e.g. building houses, which was not possible due to insufficient flood protection?
- Which add-on projects would and would not be carried out autonomously; and if so, would they be carried out earlier or later eventually than in combination with the flood protection project?
- Did natural solutions and/or add-on projects cause implementation cost savings, e.g. the lower dike heightening cost due to the creation of inundation areas; and if so, what was the amount of savings in monetary terms?
- Which societal benefits did the natural solution and/or the add-on projects generate and what was the socio-economic value of those benefits in monetary terms?
- Was the cost-benefit balance of the flood protection project positive or negative and was the balance of the add-on projects positive or negative?
- What was the determining factor for the positive or negative balance? For example, the costs of an add-on shipping project were high in combination with very limited transport benefits; or the costs of a natural solution were high – though its nature and safety benefits were rather small, i.e. limited cost savings on dike heightening because the water level reductions of an inundation area were small and temporary.
- Were the natural solutions and/or add-on projects chosen in the final design or not and why? For example, were these selected because of their implementation cost reductions or were they not selected due to their high implementation cost in relation to budget constraints?

Present values in million euro over a period of 100 years at price level 20XX and a discount rate of Y%	**One safety-only design**	**Multiple single-purpose designs**	**One integrated multi-purpose design**
Costs			
Process costs			
Implementation costs (capital and operational expenditure, including landscape integration)			
add-on project 1			
add-on project 2			
.....			
.....			
Technical flood protection measures			
Natural flood protection measures			
Flood protection total costs			
Total costs			
Benefits			
Add-on benefits			
add-on project 1			
add-on project 2			
.....			
.....			
Flood protection benefits			
Total benefits			
Project balance (benefits minus costs)			
Flood protection balance			
Add-on projects balance			

Table 2. Comparing the costs and benefits of three design modes.

With the answers to these questions, it was also possible to compose three sets of measures for each case study: one for each design mode, i.e. a set for a safety-only, multiple single-purpose and for an integrated multi-purpose design. For all case study projects, the flood protection measures were isolated as the main purpose of a project and interpreted as a single-purpose design. For the other measures it was determined to what extent these were stand-alone or fully integrated right from the start. In addition to the available cost-benefit information, extra cost-benefit information calculations were made, allowing for a comparison of the balances of a safety-only design, relevant multiple single-purpose designs, and an integrated muti-purpose design. Table 2 shows the components of the three calculations that were made for all ten case study projects. On the basis of these components the balance of the technical and natural flood protection measures and the balance of the add-on projects were unravelled. This was done to discover whether natural safety solutions (i.e. a nature-based solution that provides flood protection) and/or add-on projects enhance or diminish the benefit-cost balance of flood protection projects.

Are multifunctional designs more beneficial than monofunctional ones?

A thorough analysis of all gathered project information and cost-benefit calculations produced a mixed picture of which design mode is most socially beneficial. It also raised the question whether missing information on process costs and nature benefits could change this mixed picture.



Figure 4. Nijmegen, Lent, Gelderland: dike movement and a new canal, Spiegelwaal, for lowering the water level of the nearby Waal River, and a sloping and, wide bank for recreation. [CC Roger Veringmeier]

Mixed picture of which design mode is most beneficial – It was found that for three cases the safety-only design had the most positive balance, while an integrated multi-purpose design was more positive than several single-purpose designs. This was the case for (1) Meandering River Maas, (2) Green River Well (Figures 2–3), and (3) Dike Strengthening Tiel-Waardenburg & River Expansion Varik Heesselt. For (4) River Climatic Park IJsselpoort safety-only was also most rewarding, followed by multiple single-purpose designs. In the multiple single-purpose designs of River Climatic Park IJsselpoort, the natural safety measures were implemented later in time than in the initial integrated multi-purpose design, making them less expensive in terms of present value. What stands out with all these projects is that the natural safety solutions and/or the nature add-on project have negative balances, while other add-on projects have positive balances. This is not caused by small ecosystem benefits, but by exceedingly high cost of nature measures. Modifying the design can change this and that, as was done for River Climatic Park IJsselpoort: its initial design had a negative balance, but due to modifications the final design had a positive balance.

Although safety-only was the most beneficial design for four cases, an integrated multi-purpose design was found to be the most rewarding design for three other cases. For the cases (6) Redevelopment Boulevard Scheveningen and (9) Area Development Ooijen-Wanssum, an integrated multi-purpose design was most rewarding, followed by safety-only and several single-purpose designs. For case (7) Strengthening Hondsbossche and Pettemer Sea Defence, the order is different: an integrated multi-purpose design is followed by several single-purpose designs and safety-only. What catches the eye with these three cases is the positive balance of the add-on projects and the cost reduction due to a combined implementation: sometimes at the flood protection project, sometimes at the add-on project.

For three cases, it turned out that it was not possible to determine which of the three designs were most rewarding. Those were (5) Overtopping Resistant Dike Hoorn-Edam, (8) Dike Moving Lent, (Figure 4) and (10) Strengthening IJsselmeer dike Lelystad Kethel bridge. The reasons for this varied: for two cases the necessary cost-benefit information was missing and for one (Dike Moving Lent) a distinction between safety-only and several single-purpose designs could not be made, because the additional purposes, such as housing, were fully dependent on flood protection.

The overall conclusion from the above is that multifunctional designs can be more beneficial to society than monofunctional ones, but this is not automatically the case. It depends on which measures are combined, and if that combination leads to cost savings, and/or if add-on projects with an individual positive balance are selected. One can steer towards a positive balance by the design, i.e. by a benefit-oriented design process.

Will missing process cost change the mixed picture? – For most case study projects, the process costs, i.e. planning and design costs, were not known and could not be retrieved. This raises the question whether these costs, if known, could alter the mixed picture of what is most beneficial to society.

For the cases (1) Meandering Maas, (2) Green River Well, (3) Dike Strengthening Tiel-Waardenburg & River Expansion Varik Heesselt, and (4) River Climatic Park IJsselpoort, the answer is as follows. Process costs cannot change the fact that safety-only has the most positive balance (one simple process is always cheapest), but they could in theory render several single-purposes designs more beneficial than one integrated multi-purpose design . This is only possible when the costs of several individual simple design processes are lower than the costs of one complex integrated design process. Case study Green River Well, however, shows that the costs of an integrated process are 8% less expensive – as

percentage of the implementation costs – for the government than several single-purpose processes. This seemed to be caused by the relatively short duration of the process (see Table 1). This raises two questions:

- Can this finding be generalised, i.e. will the integrated approach always be less costly for governments?
- Will the integrated approach also be the least expensive one when the process costs of other stakeholders, i.e. the parties of the add-on projects, such as nature organisations, are included?

For three case studies, for which an integrated multi-purpose design was most beneficial, the answer is different. For (6) Redevelopment of Boulevard Scheveningen and (9) Area Development Ooijen-Wanssum, the integrated design is so beneficial that only exceedingly high integrated process costs could change the findings. For (7) Strengthening Hondsbossche en Pettemer Sea Defences, this is it not the case: here a slightly more costly integrated process could easily mean that the integrated design is no longer the most beneficial design. This indicates that it is useful to try and obtain more information on the magnitude of process costs.

Can a more elaborate determination of nature benefits change the mixed picture? – Since an integrated multi-purpose flood protection design contains either natural safety solutions such as inundation areas or nature restoration add-on projects, such as the re-meandering of a brook, there will be ecosystem benefits. Many different ecosystem benefits are possible, such as recreational benefits, housing amenities, climate benefits of carbon fixation, benefits of natural plague control, and bequest benefits like the non-use benefits of passing on nature, with all its species, to future generations.

Ecosystem benefits were determined for half of the selected case studies, but the number of determined benefits was not always complete. If this causes an underestimate of ecosystem benefits, this can wrongfully lead to the conclusion that safety-only is the most beneficial design. A complete estimate of all ecosystem benefits does, however, not guarantee that an integrated multi-purpose design will most rewarding. There are examples for which an elaborate estimation of ecosystem benefits did not lead to the conclusion that multifunctional design is most beneficial to society, e.g. (4) River Climatic Park IJsselpoort. This stood in contrast with case (5) Overtopping Resistant Dike Hoorn-Edam for which ecosystem benefit estimates support the conclusion that a multifunctional design is most beneficial. It turns out that whether combining flood protection with other functions is rewarding, depends on choosing the right measures for each particular project area (Table 3). In other words: *it remains a matter of design*.

Which factors favour multifunctional over monofunctional design?

The conclusion of this case study is that *the quality* of a multifunctional design determines whether it is more beneficial to society than a monofunctional design. This means one can steer towards a multifunctional project with a positive benefit cost balance, by a smart benefit and cost-oriented design which:

- Adds natural safety measures or add-on projects that individually have a positive benefit-cost balance.
- Adds more spatial quality than mandatory for integration in the landscape, i.e. introduces landscape architectural aesthetics by form, sight lines and material use. These architectural measures are often public space refurbishment add-on projects. These usually have relatively low costs, while they improve public space quality, leading to relatively large recreational and other benefits.

Table 3. Summarisation of findings per case study project.

	CASE STUDY	MOST BENEFICIAL DESIGN	DETERMINANT FACTORS	REMARKABLE FINDINGS
1	**Meandering River Maas (Ravestein Lith)**	safety-only, but an integrated design is more beneficial than multiple single-purpose designs	- nature add-on projects have a negative balance, even though their ecosystem benefits were accounted for - natural safety measures also had a negative balance	- recreation and shipping add-on projects have a positive balance - natural safety measure costs more than the dike strengthening cost they prevent (by allowing lower crest height) - process costs are not known
2	**Green River Well**	safety-only, but an integrated design is more beneficial than multiple single-purpose designs	- high costs of nature add-on projects - natural safety measures (side gully) costs more than the dike strengthening cost they prevent (by allowing for lower crest height)	- accounting for ecosystem benefits could mean that safety-only is no longer the most rewarding design - the process costs of an integrated design are much lower than those of multiple single-purpose designs
3	**Dike strengthening Tiel-Waardenburg & River Expansion Varik Heesselt**	safety-only, but an integrated design is more beneficial than multiple single-purpose designs	- the cost of natural safety measures surpasses the dike strengthening cost they prevent (by allowing for lower crest height)	- this project has significantly higher flood protection benefits than costs - as a result, all designs, i.e. safety-only, multiple single-purpose designs and an integrated multi-purpose design have a positive balance - process costs are not known
4	**River Climatic Park IJsselpoort**	safety-only, but multiple single-purpose designs are more beneficial than an integrated design because it postpones the river expansion, which makes it less expensive	- nature, water quality and shipping add-on projects have a negative balance, though their various benefits were accounted for - natural safety measures also have a negative balance	- recreation and energy add-on projects have a positive balance - natural safety measures cost more than the dike strengthening cost they prevent (by allowing lower crest height) - process costs are not known
5	**Overtopping Resistant Dike Hoorn-Edam**	no information for safety-only, no difference between multiple single-purpose designs and an integrated design	- nature, recreation and landscape add-on projects have a positive balance: they were designed that way (i.e. benefit-oriented design)	- provincial policy goals were analysed and measures to obtain these goals with low costs and/or high benefits were identified - only process costs of identifying add-on projects were known
6	**Redevelopment of Boulevard Scheveningen**	an integrated design is most beneficia; multiple single-purpose designs are the least beneficial	- a public space refurbishment add-on project had high benefits - a combined implementation of flood protection and public space refurbishment saves a lot of costs for the refurbishment add-on project (the area only needs to be dug up once)	- the balance of the refurbishment add-on project is only positive if implemented together with the flood protection project - only architectural process costs were estimated
7	**Strengthening Hondsbossche and Pettemer Sea Defence**	an integrated design is most beneficial, safety-only is the least beneficial	- nature and recreation add-on projects had a positive balance	- the flood protection measures had a negative balance, despite their coastal recreation benefits: the flood protection benefits were small - the add-on benefits were larger than the flood protection benefits - process costs are not known
8	**Dike Moving Lent**	unclear, because safety-only and multiple single-purpose designs were irrelevant	- natural safety measures made it possible to carry out housing and nature add-on projects	- the benefits of housing add-on projects carried the cost burden of the flood protection measures - process costs are not known
9	**Area Development Ooijen-Wanssum**	an integrated multi-purpose design is most beneficial, multiple single-purpose designs were the least beneficial	- natural safety measures and nature add-on projects lead to cost savings for flood protection measures due to combined execution - infrastructural add-on projects had a positive balance	- the flood protection measures had a negative balance despite the cost saving generated by the natural safety measures and nature add-on projects - process costs are not known
10	**Strengthening IJsselmeer dike Lelystad Kethel bridge**	unclear because the benefits of a natural lake bank are not known	- ecosystem benefits determine the outcome: when the balance of nature add-on project is positive, safety-only becomes unattractive; in this case, the process costs determine whether multiple single-purpose designs or an integrated design are most rewarding	- when the process costs of multiple single-purpose designs are only slightly higher than those of an integrated design, the integrated design becomes the most rewarding solution

- Saves process costs by combining flood protection and multiple add-on projects in such a way that the duration of the planning and design process is shortened.
- Combines safety and add-on projects in such a way the implementation costs of one of these are reduced.

Multifunctional designs are only rewarding, if one adds the right functions for the area that needs more flood protection. The functions need to connect with the characteristics of the area and with each other. This principle can also be seen with other types of projects than flood protection, such as housing or road projects. For example, a multifunctional design for a housing project in Haarlemmermeer had a negative cost-benefit balance, due to two add-on projects that did not match with the area: an expensive 'standing mast' navigation route – while there were few people owning such a vessel – and a large water catchment facility without any users. Choosing other add-on projects more aligned with the area and with the housing purpose might have led to a more beneficial multifunctional design.

Elisabeth Ruijgrok & Rob Nieuwkamer †, Witteveen+Bos

REFERENCES ■ Ruijgrok, E.C.M. & Nieuwkamer, R.L.J., (2023). *Loont een dubbele doelstelling van waterveiligheid en ruimtelijke kwaliteit? Een onafhankelijke analyse van tien voorbeeldprojecten.* Witteveen en Bos in opdracht van het Ministerie van Infrastructuur en Waterstaat. Witteveen+Bos Raadgevende ingenieurs B.V. ■ Kwadijk, F., Ruijgrok E., Jaspers, D., Bergmans, P., & De Vries, D. (2015). *Oeverdijk Hoorn-Edam: bijdrage(n) aan provinciale doelen. Een analyse van maatschappelijke baten en kosten van extra maatregelen om provinciale doelen te realiseren.* Grontmij en Witteveen + Bos in opdracht van provincie Noord-Holland. Grontmij, Witteveen+Bos Raadgevende ingenieurs B.V.

LESSONS

SOCIETAL BENEFITS OF MULTIFUNCTIONAL DESIGN

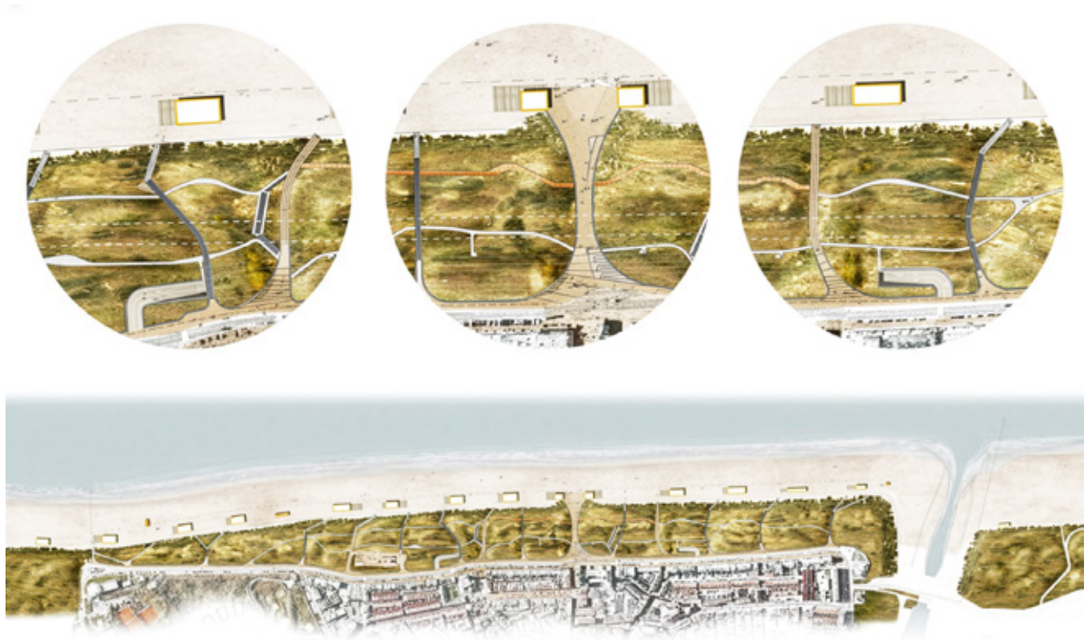
From the case study projects the following lessons can be learned:

- ***To be rewarding for society, the additions to a project need to reduce costs, generate additional benefits or both.*** The case study projects show that the sustainable design principle of *multifunctional design* does not simply mean adding functions to a design, in this case for flood protection as the core of the projects. A benefit-oriented design approach can lead to a high-quality multifunctional design that yields a positive benefit-cost balance.

- ***Cost reductions can be obtained by a combined execution of safety and other measures or by shortening the planning and design process.*** E.g. using cheap clay for dike strengthening from a nearby nature project or from a dredging project for navigation.

- ***Benefits are large: (a) when big problems are significantly reduced or when large opportunities are created for many people, and (b) when these reductions mean much to people, i.e. they are of great value to them.*** In general the value is lowest for impacts on visual surroundings, highest for impacts on physical health, and intermediate for impacts on activities. This suggests that a design which significantly enhances the visual environment for many individuals may yield greater societal benefits than one that marginally improves flood protection for a smaller group. E.g. for case (7), Strengthening the Hondsbossche and Pettemer Sea Defence, the safety improvements were modest, yet the redevelopment of public space delivered substantial benefits by creating an aesthetically appealing scenery in a heavily frequented coastal zone.

- ***The key to beneficial multifunctional design lies in adding functions that affect many people significantly.***



Spatial and engineering design of a dike and car park integrated in a dune landscape at the coastal zone Katwijk aan Zee.
[© OKRA Landscape Architects]



INTEGRATED DESIGN

THE RECONCILIATION OF SPATIAL DESIGN AND ENGINEERING

Design has existed throughout all eras and been applied to multiple domains. Since the Industrial Revolution, developments in product design have accelerated, characterised by shorter lead times and correspondingly reduced product lifespans. In contrast, the fields of transport and water infrastructure are marked by extended development timelines and the enduring physical presence of large-scale structures within both the built and natural environment.

These domains demand a fundamentally different mindset and design approach – one that emphasises integration and often requires multi- or interdisciplinary collaboration to address social values and expectations. This raises important questions: what are the origins of contemporary design as we understand it today? Is there a common design language, or do various disciplines interpret design differently? How can a deeper understanding of design principles help develop renewed perspectives on the planning and design of transport and water infrastructure?

This contribution starts with explaining the description and study of design as a scientific discipline. It describes the essence of both the engineering and spatial design approaches in terms of a logical reasoning pattern. Scientific research and 'research by design' are explained in the same terms of logical reasoning as acts of explanation or exploration. Synthesis and synergy of mono-disciplines are obtained by 'integrated design', which is illustrated by the case of the coastal zone development of Katwijk aan Zee. This contribution concludes with lessons learnt.

The emergence of design as a systematic approach

Modern design methodology – as a scientific discipline – originated in 1962 at the Conference of Design Methods in London (Cross, 1993). Of course, designs were made far before the 1960s, e.g., for the Tower of Babylon, the pyramids in Egypt, Roman amphitheatres, Medieval castles, the Panama Locks, and the Eiffel Tower, but the description and study of the design method itself is quite recent. After initial attempts to a scientific approach of design in the early 20th century, like De Stijl and Bauhaus, several modern design methods were developed and described in the early 1960's. Multiple methodologists distinguished the design steps of analysis, synthesis, development and evaluation, which differed in its final appearance. However, all had in common a sequential process subdivided into comparable steps (Visser, 2016).

Following the early research of the 1960s, a considerable amount of literature on design and design methodology was published across various fields. The diversity in these method descriptions is largely due to differences in terminology. Fundamentally, most methods are rooted in the same natural, cyclical approach to problem-solving, often described as the empirical cycle in reflection, which is defined by five core stages: observation, presumption, expectation, verification, and evaluation (De Groot, 1961).

The process of designing begins with observing the situation, after which existing knowledge and skills are used to form assumptions about the expectations and to define the steps needed to achieve a desired outcome (an aspired value). In engineering, this process explicitly includes the generation of concepts and their subsequent verification to ensure they align with the expectations. Ultimately, the problem-solver reflects on the outcome of the thought process by asking: "What did I learn from this?" and "How can I apply this experience, possibly in a next design cycle?" This process is grounded in logical reasoning and psychological theories, with protocol analyses showing that it is both universal and inevitable (De Groot, 1961).

A design method should be regarded as a tool to achieve a goal – not as the goal itself – and how it is used depends on the designer's level of expertise. While the intuitive nature of the design process is beneficial for novice designers and simpler tasks, more advanced and complex problems require a deeper set of skills, knowledge, and understanding. Dreyfus (2003) identifies six levels of expertise, from novices to experts and visionaries. Novices will follow the method closely and treat the features of an object as fixed and defined by experts. Experts, on the other hand, respond more intuitively to situations and take the right actions immediately. Visionaries have mastered the method as a tool and can adapt its elements. They expand their knowledge and explore other fields, even creating new approaches. At this level, Lawson and Dorst (2009) characterise designing as "one of the most complex and sophisticated things we can do with our minds."

According to Siers (2004), the main advantages of a systematic design method are:

- one does not jump to solutions too soon,
- it offers a way to organise the design process,
- a good overview of design activities is obtained,
- there is only a small likelihood that essential aspects are overlooked,
- it facilitates decision-making,
- the chance increases that an effective product or system is created.

Systematic approaches also have their drawbacks, particularly when they provide limited options for addressing ill-defined and complex problems, which hinder creativity and reduce opportunities for learning from the design process. These shortcomings have motivated architects to develop their own approach – establishing design as a scientific discipline.

The following sections describe the essence of both the engineering and spatial design approaches, compare them to the process of scientific research, and explains how *integrated design* and *research by design* – as approaches – can be understood in terms of a logical reasoning pattern.

What is design?

Defining 'design' can be considered as a discipline on its own, but a practical viewpoint is chosen for the purpose of this design guide. In this context, design can refer to a process, or to the product of that process. This contribution focuses on design as a process, and more specifically as the process of creating an optimal plan or convention for realising a product, structure or system that satisfies a need. Thus, value is added by solving a problem. A problem in design is the discrepancy between the present or future actual situation and the desired situation. The definition emphasizes the application of knowledge of natural, social, or psychological processes for the benefit of society. Mick Eekhout, therefore characterised design as "the tunnel through which the results of scientific research are brought to society." (Van Genderen, 2007).

A fundamental philosophy of design is described by Taeke de Jong (De Jong, 1992). He distinguishes three types of futures that can be obtained by means of different actions (Figure 1):

1. *Possible futures,* do not arise 'automatically' from a system of causal relationships; they must be designed. Conditions must be met to enable possible futures, but they are not sufficient to create these futures.
2. *Likely futures*, in contrary, are related to causality, while possibility is a condition for likely futures.
3. *Desirable futures* are related to willing and choosing.

Designs, according to De Jong, do not necessarily create a certain future, experience of use, they merely enable them.

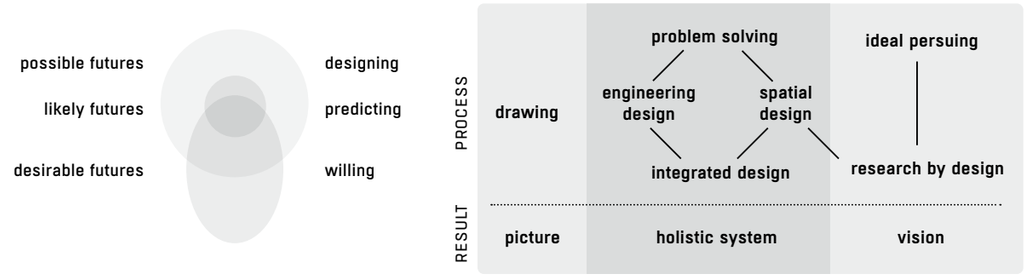


Figure 1. Motives related to the three types of futures according to De Jong (1992). / Figure 2. Positioning of types of design based on the notions of Taura and Nagai (2009). [Mark Voorendt]

Depending on the specific goals and application areas, diverse types of design can be identified, including industrial, urban, engineering, and product design. While these categories often overlap, Taura and Nagai (2009) propose a more rigid classification, distinguishing between 'drawing', 'problem-solving', and 'ideal pursuing':

1. *Drawing*: the expression of images through pictures or sketches, which is intricately linked to art. A more accurate term for this design category would be 'artistic drawing', because this type of drawing can be used as tools in the other two design categories. However, artistic drawing should not be considered a form of design, since design is primarily functional rather than contemplative (Forsey, 2013). According to Taura and Nagai (2009) it does not produce truly novel outcomes, while the drawing process appears creative; it just translates an abstract image already formed in the mind into a tangible figure or shape. Unlike the other two categories, drawing does not necessarily aim for realistic 'solutions', making it fundamentally different in approach.
2. *Problem-solving:* the procedural nature of this type of design is primarily applied to activities focused on finding solutions to real or anticipated problems. A problem is defined as the gap between the current state and the desired goal, and the process of developing a solution is essentially the design process itself.
3. *Ideal pursuing*: the desire to create an ideal environment is the driver for ideal pursuing, rather than the urge to solve specific problems. It involves the creation of ideas that align with future possibilities – visions of what could be, which can only be speculated upon by humans. Ideal pursuing resembles problem-solving if a realistic outcome is desired because the difference between the realistic present and the idealistic future can be regarded as a 'problem' according to the above definition.

The general form of a systematic process to conduct a problem-solving design is called a design method. Unlike mathematics, it is ambiguous: in design there is generally more than one valid solution that solves the problem. The outcome of a design – the solution – highly depends on the chosen requirements and evaluation criteria, and the creativity of the design team. The problem-solving approach related to infrastructure is applied in two main design approaches:

- *engineering design*, often briefly indicated as 'engineering',
- *spatial design,* usually briefly indicated as 'design'.

The three classes of design as distinguished by Taura and Nagai (2009) can be used to position the types of engineering design, spatial design, integrated design, and research by design (Figure 2). These types of design are explained in the following sections in terms of a logical pattern of reasoning.

The positioning of design as a way of logical reasoning

Dorst (2011) describes the design process as a logical way of reasoning, through which a basic pattern can be applied to problem-solving in scientific research and design. The 'problem' in science consists of a deficit in knowledge, while in design it is the discrepancy between the present or future actual situation and the desired situation. Dorst starts with explaining the basic pattern of reasoning used by humans in problem-solving, by comparing settings of knowns and unknowns in the equation:

what + *how* → *result*

In other words: an object, or a system (the 'what'), behaves according to a working principle (the 'how'), leading to an observable 'result'. The working principle can for example be a law of nature, a method or technique. The equation can be clarified with an example: a constellation of a tree, an apple and the planet earth (the 'what'), together with the working principle of gravity, Newton's law of universal gravitation (the 'how'), leading to the apple falling from the tree on the earth surface (the 'result'). This basic pattern of reasoning is used in the following sections to explain the difference between engineering design and spatial design, as well as the difference between scientific research (science) and design.

Abduction characterises design – The basic pattern of logical reasoning can be used to explain the processes of engineering design and spatial design. An essential step in design reasoning is called 'abduction', which is a form of logical inference that looks for the simplest and most likely conclusion from a set of observations. It was formulated and advanced by American philosopher and logician Charles Sanders Peirce, amongst others, beginning in the latter half of the 19th century (Peirce, 1903). Abductive reasoning, unlike deductive reasoning, yields a plausible conclusion but does not verify or evaluate the result of that reasoning. It involves the creativity and intuition of the designer and some knowledge about how our world 'works'. It only results in potential concepts that might or might not work. Therefore, an extra design step is needed to verify whether the concepts generated by abduction meet the requirements. In a sense, it is a trial-and-error, iterative approach. The nature of the abduction is different for engineering design and spatial design and therefore engineering abduction and design abduction are explained below.

Engineering abduction – Abduction can be considered as 'the logics of what could be'. It is the creation of forms, shapes or objects that could potentially solve the problem. In Dorst's scheme of reasoning, engineering abduction can be represented as:

what? + *how* → *aspired value*

So, during an engineering design process, the objects, or systems (the 'what'), will have to be found, that act according to known working principles to obtain a predefined aspired value. To give an example: In case of two disconnected stretches of water, the aspired value is the possibility for vessels to overcome this water level difference to create a waterway transport system (without affecting the levels in the stretches). The working principle consists of influencing water levels by letting water flow from high to low, due to gravity. The object to be designed then is a lock chamber with gates in which the water level can be adjusted to both water stretches, plus all additional structural components like lock heads, a levelling system, guide walls, bottom protection, etc.

In engineering design, the working principles are supposed to be known, as they concern the laws of physics, but knowledge of these principles can still be extended to create more efficient designs. For instance, the impact of breaking waves with air inclusions on coastal walls with parapets is still not very well known. The lack of knowledge about the physical working principles means either that ways must be found to deal with the uncertainties, or that more research will have to be done to improve the design.

Design abduction – Design abduction, which is typical for spatial design, resembles engineering abduction, but next to the what, the how (the working principle) is unknown as well:

what? + *how?* → *aspired value*

The working principles in spatial design consist of psychological and sociological processes, which are usually much less predictable than the working principles of engineering designs (the physical processes). The problem in spatial design is that there are too many unknowns to solve the basic equation of logical reasoning. The desired result is given, but it is unknown what configurations, objects or systems are needed to perform the working principle, and the working principle is unknown as well. Therefore, spatial designers use 'frames' that assume an unknown, not (fully) understood working principle to lead to the aspired value, so that a what can be created:

$$\textit{what?} + \frac{\textit{how?} \rightarrow \textit{aspired value}}{\textit{frame}}$$

This twofold creative process requires spatial designers to develop proposals for both the 'what' and the 'how' and evaluate them together. Schön (1983) already used 'framing' for the creation of new standpoints that help solving a problematic situation. Frames are – in essence – collections of statements that involve a particular perception of the problem situation and underlying working principle potentially guiding the solution. While frames are often represented by simple metaphors, they consist of complex sets of statements. The most logical approach to tackle this complex problem is working backwards, starting with the only 'known' element in the equation: the 'aspired value' that needs to be created. From there, a frame can be adopted or developed. This initial framing is basically a form of inductive reasoning, working back from potential aspired values. Once a viable, promising, or at least intriguing frame is proposed, the designer can move on to an engineering abduction form of approach, focusing on designing a 'thing' (whether an object, system, or service) that will complete the equation. Only once the equation is fully formed, its value must be evaluated. The next step is to reason forward, using deduction to assess whether the combination of the 'what' and the working principle is effective enough to generate the aspired value (Dorst, 2011).

It is clear that with too many unknowns, first the equation itself should be sorted out ahead of the common design approach. Starting from the values – as social needs – it refers both to 'design-thinking' as well as 'second-order' learning. This requires an investigative and reflective attitude with a clear focus on social values, and sufficient capabilities and experience to deal with uncertainties. To find out whether the created 'what' will indeed lead to the aspired value, much experimenting and simulations are needed. Especially the verification is therefore more complicated than for engineering designs.

De Boer and Cavallo (2024) point out that the basic way of reasoning in a spatial design process – as formulated by Dorst (2011) – needs to be extended for practical application. They argue that the context cannot be left out, because multiple interests, multiple systems, multiple scales, etc. are involved. It thereby represents a plurality of physical, social, governmental, economic, financial, technological, legal, cultural, historical, and ecological aspects. In addition, De Boer and Cavallo advocate for including the initial aspired value – as the purpose – in the equation. In an ideal case, the obtained value matches the purpose of the client, but the actual outcome of a design process, the realised value, is not necessarily what was aimed at. De Boer and Cavallo therefore formulate the way of reasoning for spatial design as: *PURPOSE (objectives) steers WHAT (object) x CONTEXT (plural) x HOW (working principle) leads to VALUE (outcome).* This implies the inevitable need for iterations.

Scientific research and research by design in patterns of logical reasoning

The main difference between scientific research and design is that scientific research aims at a better understanding of reality (increasing knowledge), while design aims at changing reality (creating or modifying something). The act of abduction, as applied in design methods, is lacking in the scientific research method. This makes the research method principally unsuitable for the creation of solutions for undesired situations. Instead, scientific research can be characterised by two ways of logical reasoning: induction and deduction.

Induction – An inductive way of reasoning aims at finding the working principle. By knowing the objects and by observing the results of an experiment, the relation between the objects can be studied:

what + how? → result

Inductive reasoning uses arguments (premises) to give evidence for the truth of the conclusion. This is typical for observed facts, for instance obtained through laboratory experiments. The starting point of induction consists of observations, and it leads to generic principles. Although induction is often considered as a typical characteristic of scientific research, it can also be recognised in a design method, namely in the problem and system analysis phase, where the current situation is mapped out.

Deduction – In a deductive way of reasoning, the result can be found, as the what and the how are known:

what + how → result?

Deductive reasoning is a way of speculative thinking, from general principles to particular cases. Hypotheses are commonly used to make assumptions in order to make the conclusions of inductive or deductive reasoning more general. To find out whether these hypotheses are valid, they are verified by other observations. This way of reasoning applies to questions with only one correct answer, and that answer can be obtained with certainty, if all implications (physical laws, propositions) were known. However, for instance, if the what consists of wet streets, and the how is 'it rains', it might lead to the wrong conclusion, the 'result', that 'wet streets are always caused by rain'. Therefore, Popper (1935) proposed a scientific method based on falsification, in which science progresses when a theory is shown to be wrong, and a new theory is introduced that better explains the phenomenon. Like induction, deduction cannot exclusively be attributed to scientific research, as it can be recognised as the creation of concepts in the design approach, in which the concepts can be considered expectations or hypotheses. In design methodology, the activity of deduction is called 'synthesis', as it brings together the acquired information obtained in the phase of analysis to create concepts. This brings us to the research by design approach as a knowledge-seeking activity in which design and design-thinking are constituent elements.

Research by design – Research by design is an approach where the process of designing or creating something serves to explore, evaluate, or generate knowledge. It combines creative design practices with research, so that the act of designing is both the method and the outcome of the research process. The European Association for Architectural Education (EAAE) defines research by design as "any kind of inquiry in which design is the substantial constituent of the research process". This approach is often used in fields like architecture, urban design and planning, and product design, where the design itself can generate insights, hypotheses, or responses to research questions. It is becoming a more obvious and applied approach for exploring future implications of issues and dealing with uncertainties like societal developments, climate change effects, and related system transitions such as energy, water, and mobility, all of which have a substantial spatial component.

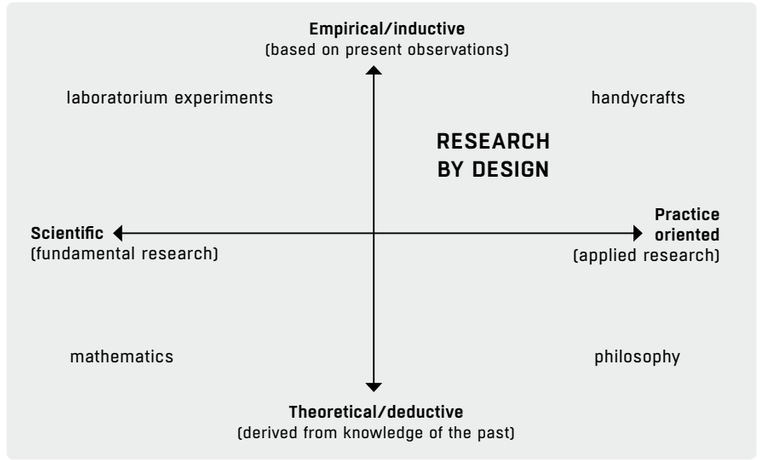


Figure 3. Positioning of research by design in the scientific spectrum, according to Sijmons. (Modified from: Faste & Faste, 2012)

In terms of the basic pattern of logical reasoning as presented by Dorst (2011), research by design mostly resembles the design abduction pattern (*what? + how? → aspired value)*, but the aim is not making a design but doing research. It consistently considers multiple alternatives to systematically study the result (for example as a way of future exploration) or to study the working principle, the how. A useful application of research by design would be the creation of a theory on frame development: under what conditions would a frame be likely to work and how can it be applied explicitly?

Research by design can be considered as a way of 'ideal pursuing' as described by Taura and Nagai (2009) or as De Jong (1992) puts it: as a way of enabling possible futures by comparing multiple design concepts – thus exploring what potential values can be obtained. Exploring possible futures implies making assumptions on aspired values in times yet to come. After all, paradigm shifts are likely to happen, but because of the absence of "a clear dominant paradigm and an integrated, multidisciplinary and inter-sectoral approach, it will be a challenge to address a multitude of issues that all claim space…" (De Boer, 2022). Basically, the design pattern for future exploration looks like:

what? + how? → aspired value?

This seems an impossible task, because there are only unknowns. Even the frames of design abduction offer no solace here. However, if a specific aspired value is assumed, it is possible to form a frame with the how, and then a what can be found. This can be done for multiple aspired values, enabling the exploration of future values. In this way, research by design provides insight to policymakers who can see the concrete consequences of their choices.

Sijmons positioned research by design in the practice-oriented and empirical side of the scientific spectrum (PBL, 2024; Figure 3). This is correct for present issues to resolve, but for uncertain developments in boundary conditions, like sea level rise, a research by design approach can be also expanded towards the 'theoretical/deductive' side of the quadrant, because deduction is required to assume future conditions, aspired values and working principles. This is characteristic for complex design tasks like the anticipation to uncertain developments and the fear of locking in by particular measures, especially for flood protection of deltaic areas dealing with sea level rise.

Research by design is an approach that can bring together short-term and long-term interests in spatial policy. It is applied to the exploration and shaping of spatial policy, because it enables the integration of quantitative, qualitative, and practical knowledge. The integration of and inter-

Engineering design	Spatial design
Linear, sequential process	Cyclic, iterative process
Prescriptive	Descriptive
Problem is well-defined	Problem is ill-defined
Problem is decomposable into parts	problem is not decomposable
Analytical character	Experimental, learning character
Normal abduction	Design abduction

Table 1. Characteristics commonly attributed to engineering and spatial design methods. [based on Stolk, 2016]

action between disciplines takes away the criticism of research by design that it is 'pie in the sky', because it assures the verification and evaluation of concepts by the process. [Research by Design Framework, page 108]

Integrated design as synthesis and synergy of mono-disciplinary approaches

Designing transport and water infrastructure in built-on areas requires a systematic and logical approach to streamline activities, ensuring the process is efficient, effective, and transparent. Design activities must be phased to organise the entire process effectively and all (sub)systems must be incorporated into the design. On the other hand, adopting a learning, experimenting, and reflective approach is needed for understanding complex, often poorly defined and ill-structured problems – along with their relationship to the surrounding environment. Therefore, an integrated approach is recommended, combining the systematic problem-solving strengths of engineering design with the creativity and learning-oriented approach of spatial designers (Table 1). The drawbacks of both methods should be avoided.

Upon reviewing Table 1, it becomes clear that many of the supposed and depicted differences are not as significant as they initially seem. The engineering method, both in education and practice, is highly iterative and cyclical, like spatial design. In engineering, it is common to revisit design steps due to insights gained during the process or to new information acquired along the way. Additionally, design steps are often repeated at increasing levels of detail, suggesting a cyclical nature. Furthermore, hydraulic engineering problems for example are often ill-defined, especially in large-scale projects involving many stakeholders and complex systems. In this regard, engineering does not differ significantly from spatial design. [Systems Engineering, page 304]

This observation reduces the differences to the following characteristics: the engineering design method is decomposable, analytical, generally abductive, and prescriptive, while the spatial design method is non-decomposable, experimental, design-abductive, and descriptive. These four characteristics are closely related from a cyclic perspective, making it easier to combine both approaches. Additionally, the two methods seem largely complementary, as the strengths of one approach offset the weaknesses of the other, and vice versa. The challenge lies in creating a combination that strengthens both methods, rather than undermining them.

The basic engineering design stages outlined by Roozenburg and Eekels (1995) are regarded as essential and logical for an efficient and effective design process. The advantage of this approach is that it is intuitive while following a logical sequence of necessary design phases. As a result, these stages are adopted in the combined method and by the collaboration of both engineering and spatial designers from the start and during the whole process. However, the challenge is to avoid making the process too analytical in the first stages, as this can unnecessarily limit the potential solutions. At the same time, the method should not be confined to purely creative or generative activities, as this could result in unfeasible solutions, particularly for complex problems. The iterative nature of the

engineering method allows for experimentation and refinement of earlier design steps, which can be achieved by integrating both approaches. An integrated design approach as applied in the minor Integrated Infrastructure Design at TU Delft is also explained in this design guide. [Integrated Infrastructure Design Method, page 290].

To illustrate the synergy between the two design methods from an integrative perspective, the case of a coastal zone development is discussed, in which the water, transport and spatial systems all play a role.

The coastal zone development in Katwijk aan Zee: In search of a suitable form of integrated design

Purpose of the project – A typical example of a project in which spatial design and engineering were integrated is the coastal zone of Katwijk aan Zee. The town is situated along the Dutch North Sea coast, near the original mouth of the river Rhine. By the end of the 20th century, part of Katwijk was found to be inadequately protected from storm surges, leaving around 3,000 residents at an unacceptable flood risk. Moreover, the primary flood defence was expected to weaken by 2050, endangering a large area of the province of South Holland. As a result, Katwijk was identified as a weak link along the Dutch coast, requiring immediate action (RIKZ, 2003).

An additional, urban challenge was the pressure on local parking – particularly along the boulevard, where parking occupancy reached 120% on weekends and 90 to 100% on weekdays – creating significant strain on the local transport system. Most of the beachside parking spaces were occupied by service vehicles, company cars, business owners, and tourists, leaving little room for residents, despite two nearby car parks (Mobicon Concordis Group, 2008).

The assignment was to enhance the flood defence to meet the flood risk standards and at the same time address the parking issue. Maintaining the area's spatial quality was a main consideration, with attention given to preserving the dune landscape, the visual connection with the sea, and the accessibility of the beach (Kustwerk Katwijk, 2013)

The motivation for making an integrated design – The idea for an integrated design started with the introduction of the 'climate dike' concept at the beginning of the present century by the water innovation programme WINN of Rijkswaterstaat. It served as a catch-all term for dike reinforcement measures due to climate change. The concept evolved into the 'delta dike' concept, coined in 2006 by the Sustainable Coast Development committee. This concept was later adopted by the Climate Dike programme that aimed at multifunctional use of dikes, to better enable future dike reinforcements. In the beginning of 2008, the concept was adopted by the CURNET foundation – and later included in the Multi Dike programme – to involve more parties in the development. As a result, the municipality of Katwijk and the Coastal Flood Protection Project Katwijk ('Hoogwaterbeschermingsproject Kustversterking Katwijk') joined the programme. Later, the province of South Holland and the Water Board Rijnland joined as well (CURNET, 2011). [Flood Defences, page 280]

The coastal protection of Katwijk was interesting for the Multi Dike programme, because it allowed very well for exploring innovative solutions to achieve multifunctional use of flood defences. This can be seen as a form of research by design. The programme was the first to develop an integrated, innovative concept with full integration of flood protection and urban functions. This would not only result in spatial optimisation, but also in financial benefits (CURNET, 2011).

A first integrated design – An underground car park with a diaphragm retaining wall at the seaside – as an erosion protection – was chosen for the final elaboration of the Multi Dike business case (Figure 4). The integration of both functions into one structure was not a strict requirement but was preferred because it offered a considerable improvement of the relationship between the beach

and the village through the reduction of the distances and the height. By using a vertical wall instead of a horizontal dune, or a dike-in-dune solution, a large amount of space would become available for shared use of the dune strip by third parties. This would eliminate the necessity of beach nourishment.

The initially proposed structure was relatively simple and the execution would require relatively little time and space, causing considerably less hindrance and nuisance in Katwijk. There would be good possibilities for future coastal reinforcement, offering maximum flexibility in the implementation of the co-use. The innovative concept involved positive integration effects and offered spatial and economic development opportunities for Katwijk aan Zee. The concept allowed for food outlets and other functions to be integrated into the structure, so that the beach pavilions would not be situated on the beach and would no longer have to be removed in winter, as usual. These positive social effects would not only be of local significance, but also have a regional and, to a limited extent, even national impact (CURNET, 2011).

This solution would have saved the costs of beach nourishments and implied substantially lower management costs for the national government and the Water Board Rijnland. It would also have yielded major social and economic benefits for the municipality of Katwijk, its citizens and its entrepreneurs. Because the structural character of the lower management costs and the higher social benefits, the concept would have generated a financial advantage during the life cycle that would possibly exceed the savings on investment costs (CURNET, 2011).

The realized design – The final design for the Katwijk multifunctional coastal defence and parking, however, deviates from the concept developed by the Multi Dike programme due to governance issues – mainly concerning the division of ownership and liabilities in view of the risks in case of failure of flood protection. The Municipality of Katwijk owns the car park and the Water Board Rijnland owns the flood defence. The division of costs for maintenance was another issue, as well as the difference in design lifetimes of the structures: 50 years for the parking garage and 100 years for the flood defence (Figure 5).

The realized solution therefore has a separate dike embedded in the dunes, instead of an erosion-proof diaphragm retaining wall as part of the car park. The ownership and responsibilities for the car park and the flood defence are completely separated. Because of the separation of functions in different structures, there is no dispute now about who pays what part of the construction and maintenance costs. Inspection, maintenance, and repair of the flood defence (as far as needed) can now be executed independent of the car park management. Its structure completely resides outside the influence zone of the flood defence and therefore does not influence the risks of flooding of the hinterland. [Risk Assessment, page 198]

Although the car park and the flood defence are not structurally integrated, they together contribute to a holistic experience, because both parts are spatially integrated in the same dune landscape. The ‘aspired value’ is realised but with a different combination of the ‘what’ and ‘how’ proposed earlier by the Multi Dike programme. The project includes nature and recreation and offers spatial quality for citizens and visitors, and all aspects are considered. This example can certainly be seen as a successful example of an integrated design. [Coastal Zone Katwijk, page 148]

It can be concluded from the lenses introduced by this design guide that the functionality and social values have been delivered so that the choice of the intervention scale has resulted in landscape integration. In terms of perception, the parking garage is both invisible and recognizable through the user entrances and the spatial quality is good (high usage, experience and future value due to the raised dike and widened beach). [Integrated Infrastructure Design Lenses, page 182]



Figure 4. First design alternative for the multifunctional coastal defence of Katwijk aan Zee. [© DP6 architectuurstudio]

The inevitability of integrated design for a complex and uncertain future world

Designing a future world is a complex task due to the multitude of systems and scales involved, and the uncertain developments that the future will bring, as well as insufficient knowledge of socio-economic systems. Design-thinking, designing, and collaborating with multiple disciplines from necessary competencies – given the many transitions that are coming to society and the physical world – for those who want to contribute to this domain. Integrated design as design method and research by design as research approach – both within a transdisciplinary context – provide a basis for solving the complex social issues within the spatial and infrastructure domains that the modern world is facing. The process of integrated design allows for creating new concepts that are likely to achieve the aspired value and thus enable a certain future. The process must be well organised and managed because of its internal complexity and entanglement with many stakeholders, taking a multitude of interests, laws, and regulations into account. Integrated design thus allows for taking all the lenses into account.

Mark Voorendt, TU Delft

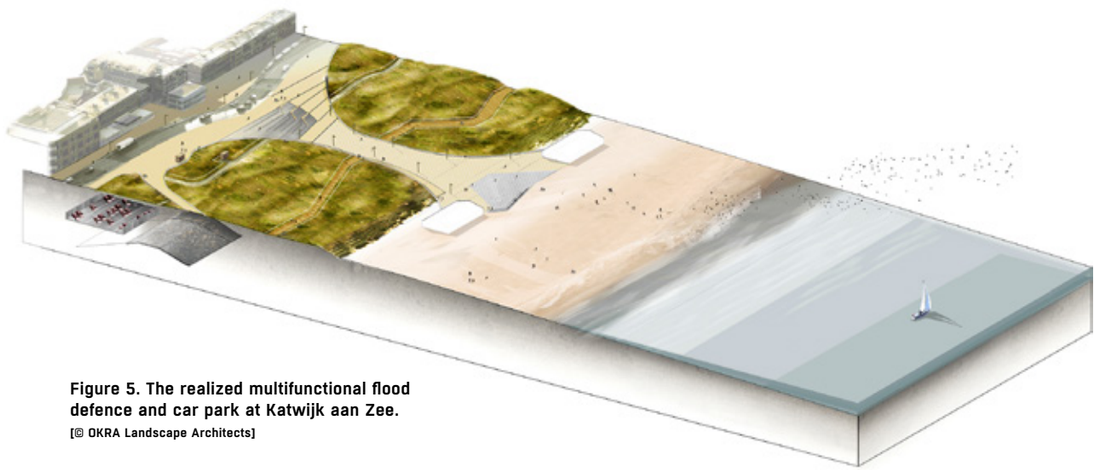


Figure 5. The realized multifunctional flood defence and car park at Katwijk aan Zee.
[© OKRA Landscape Architects]

REFERENCES: Cross, N. (1993). A History of Design methodology. In: De Vries, M.J., Cross, N., & Grant, D.P. (eds.), *Design methodology and relationships with science, 15-27* Springer ■ CURNET (2011). *Business case Multikering Katwijk "Optimale balans tussen waterveiligheid en ruimtelijke ordening".* CURNET programma Multidijk / Consortium Businesscase Multikering Katwijk ■ De Boer, H. (2022). The need for a paradigm shift and integrated approaches for a future(proof) built environment. In Berlingieri, F., Cavallo, R., Corradi, E., & De Boer, H. (eds.), *Design actions for shifting conditions, 37*-52. TU Delft OPEN Books ■ De Boer, H., & Cavallo, R. (2024). City making in times of transition. *Proceedings of the International Conference on Changing Cities IV.* Rhodes Island. ■ De Jong, T. (1992). *Kleine methodologie voor ontwerpend onderzoek*. Boom ■ De Groot, A.D. (1961). *Methodologie. Grondslagen van onderzoek en denken in de gedragswetenschappen.* Van Gorcum ■ Dorst, C.H.K. (2011). The core of 'design thinking' and its application. *Design Studies, 23*, pp. 521–532 ■ Dreyfus, H.L. (2003). *The Spinoza lectures.* University of Amsterdam ■ Faste, T., & Faste, H. (2012). *Demystifying "Design Research": Design is not research, research is design.* IDSA education symposium. https://www.academia.edu/3019956/Demystifying_Design_Research_Design_is_Not_Research_Research_is_Design ■ Forsey, J. (2013). *The aesthetics of design.* Oxford University Press ■ Kustwerk Katwijk. (2013). *Projectplan kustversterking Katwijk*. Technisch rapport. Hoogheemraadschap van Rijnland ■ Mobicon Concordis Group. (2008). *Stilstaan bij parkeren. Parkeerbeleid Katwijk 2008 – 2018.* Technisch rapport. Gemeente Katwijk ■ Peirce, C.S. (1903). Pragmatism – The Logic of Abduction. in: *Collected Papers of Charles Sanders Peirce, volume 5: Lectures on Pragmatism and Abduction,* pp 195–205 ■ Planbureau voor de Leefomgeving (PBL). (2024). *Verslag seminar 'Ruimtelijke samenhang in transitieopgaven van 4 april 2024* ■ Popper, K.R. (1935). *Logik der Forschung.* Verlag von Julius Springer ■ RIKZ. (2003). *Naar integraal kustzonebeleid. Beleidsagenda voor de kust.* Technisch rapport Rijkswaterstaat, Rijksinstituut voor Kust en Zee ■ Schön, D.A. (1983). *The reflective practitioner: How professionals think in action.* Temple Smith ■ Siers, F.J. (2004). *Methodisch ontwerpen volgens H.H. van den Kroonenberg.* Noordhoff Uitgevers ■ Taura, T. & Nagai, Y. (2009). A definition of design and its creative features. In: *Proceedings of International Association of Societies of Design Research* ■ Van Genderen, P. (2007). Introduction. In Eekhout, M., & Tomiyama, T., (eds.), *Delft Science in design 2, volume 3 of Research in design,* 11–12. Delft University of Technology, IOS Press ■ Visser, J.L. (2016). *Design methodological spectrum at Delft University of Technology.* Work report. TU Delft.

LESSONS

THE RECONCILIATION OF SPATIAL DESIGN AND ENGINEERING

When zooming in on the design and practice related activities, the following lessons can be learnt:

- ***Integrated design can turn back the present divergence of specialising and fragmenting.*** It can re-unite the spatial and engineering disciplines at the front-end of problem and project definition.

- ***Integration requires collaboration.*** Multiple sectors, stakeholders, and disciplines must be involved in complex and ill-defined design challenges to properly define the problem and aspired values.

- ***Pair intuition with thoroughness.*** Design-thinking – starting with aspired social values and from a system perspective – can open-up prospects for resolving problems when more than one unknown must be dealt with, in case the 'what' and 'how' are not evidently clear.

- ***Strive for social benefits.*** Integrated design can lead to lower costs for construction, management, inspection, and maintenance and can yield major social benefits for the community.

- ***Integrated design is demanding.*** At the same time, an integrated design can be a challenge for governance regarding responsibilities, possibilities of inspection, repair, and financing.

- ***Integration can happen at different levels.*** An integrated design approach does not necessarily lead to integration of all functions into one structure as the best and only result. Functions can also be integrated at a system level or spatial scale as one coherent design.

- ***Harness the power of design for knowledge development.*** Research by design is appropriate for investigating present issues as well as for future exploration in which design is the main activity. It allows the 'what', the 'how' and even the future 'aspired value' to be uncertain. This supports policymakers in dealing with speculations – grounded by scenarios – to explore and imagine situations for a better understanding of the gap between present and potential future conditions and situations.



FEATURED DESIGN: COASTAL ZONE KATWIJK

SPATIALLY INTEGRATED FLOOD DEFENCE AND CAR PARK

Can we intervene in a landscape while preserving its character? Can we add functions as a flood defence and car park in a seaside resort while contributing to its spatial quality?

Characteristics

The coastal zone of Katwijk aan Zee was reshaped to better protect the hinterland against storm surges from sea and meanwhile to provide extra parking places for cars – while preserving the spatial quality of the popular seaside resort. The weak section of the dunes, with a length of about 900 m, was reorganised and expanded from 30 to 120 metres width. To maintain the spatial quality of the dunes and the village's relationship with the public beach – while minimizing the amount of sand required to resist erosion during severe storms – the beach was extended by approximately 100 metres. A dike, embedded in the dunes, was added to stop ongoing erosion and thus provide sufficient protection against flooding.

A subterranean car park with a length of 500 metres and a capacity for 660 cars was constructed between the dike and the boulevard. It contains public toilets and parking spaces with charging points for electric cars. The car park is equipped with a signalling system for finding free parking spaces (green and red lights in the ceiling). The main and secondary entrances and driveways are naturally 'incorporated' into the dune landscape. The design uses colours and materials that are typical of Katwijk aan Zee and the dune landscape. The total costs of the project were estimated at about 78 million euros.

Significance

The integrated design is unique in the Netherlands. It achieves a high quality in terms of landscape, ecology, technology, and architecture. In particular, the spatial quality has been improved by integrating the flood defence and car park in the dune landscape, while recreation and ecology were equally important parts of the design. This has been acknowledged with several awards, including the German Design Award 2017, the IPI Award of Excellence 2017, and the Best Building of the Netherlands 2016.

Mark Voorendt, TU Delft

LOCATION: Katwijk, South Holland ■ **CLIENT:** Municipality of Katwijk aan Zee, in cooperation with Water Board Rijnland and Rijkswaterstaat ■ **ARCHITECTURE/URBAN DESIGN:** OKRA Landscape Architects, Royal HaskoningDHV, ZJA Architects & Engineers ■ **ENGINEERING:** Ballast Nedam, ZJA Architects & Engineers, Arcadis ■ **CONSTRUCTION:** Ballast Nedam, Rohde Nielsen ■ **REALISATION PERIOD:** 2013-2015.

FURTHER READING ■ Arcadis. (2013). *Projectplan Kustversterking Katwijk.* Hoogheemraadschap van Rijnland, Gemeente Katwijk en Provincie van Zuid-Holland ■ ZJA Architects & Engineers. *(n.d.). Parking garage Kustwerk Katwijk, Katwijk. Coastal reinforcement with underground parking.* ZJA Architects & Engineers.

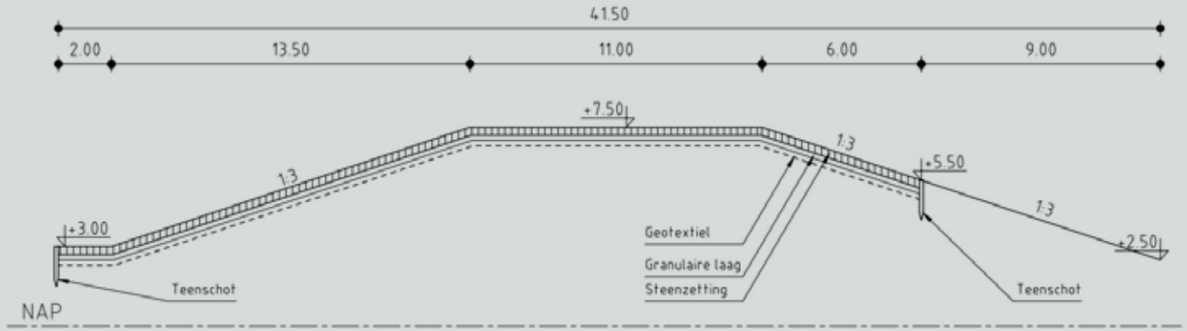
Previous pages: aerial view of the coastal zone of Katwijk aan Zee with the embedded dike in dunes. On the left the boulevard and the car park entrances, in the middle the bicycle and pedestrian pathways, and on the right catering on the beach. [© Okra Landscape Architects]



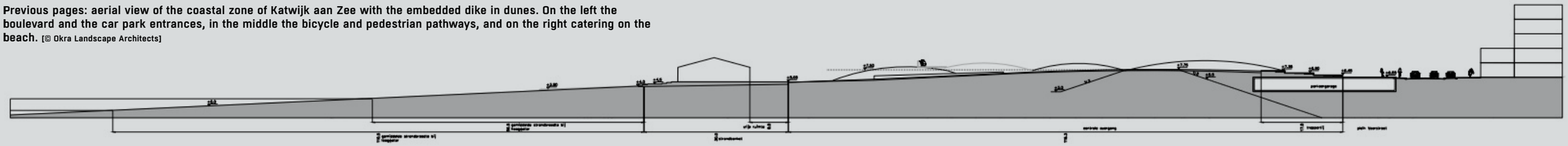


Left: Province of South Holland. [CC Jan Willem van Aalst] / Right: map of the coastal zone at Katwijk aan Zee (NW direction on the top). The thick red line represents the dike in dune structure. The thick blue line enclosed by the dike and boulevard is the underground car park. / Below: top-view drawing of the coastal zone. The structures are embedded in the dune landscape. [© OKRA Landscape Architects]





Above: Detailed cross-section of the dike that is embedded in the dunes. [© Arcadis] / Below: Cross-section of the beach, dunes, and parking garage (sea on the left). [© OKRA Landscape Architects]















Left page: dike and car park construction (left). [© Rijkswaterstaat, Maarten van Rijn] **/ Top: boulevard and pedestrian entrance of the car park, spatially embedded in the dune landscape.** [© OKRA Landscape Architects] **/ Below: recreational cycle and foot paths integrated in the dune landscape.** [© OKRA Landscape Architect / © Rijkswaterstaat, Maarten van Rijn] **/ Spacious and well-lighted interior of the car park.** [© Rijkswaterstaat] **/ Southern car entrance to the car park.** [© OKRA Landscape Architects]











Six train stations of the Dutch policy of Nationale Sleutelprojecten (NSP) for station renewal: (top) Amsterdam Zuid, ZJA Architects & Engineers. [© Zwartlicht]; (middle-left) Station Breda, Koen van Velsen architecten. [© Rene de Wit]; (middle-center) Rotterdam Centraal, Team CS (Benthem Crouwel Architekten, MVSA Architects, West 8). [© Jannes Linders]; (middle-right) Arnhem Centraal, UNStudio. [© Hufton+Crow]; (bottom) Utrecht Centraal, Benthem Crouwel Architects. [© Jannes Linders]



BEYOND MOBILITY

WHY STATIONS MATTER IN THE ARCHITECTURE DISCOURSE

Mobility is not merely a service provided by architecture, as expressed in infrastructure; rather, it is both actively shaped by architecture and, in turn, shapes architectural practice. With the evolving role of stations for sustainable mobility and urban (re)development, one can ask to what extent architectural education keeps track with these transitional developments. How can one interpret the function and meaning of a station and its life span within a multitude of contexts? Which mindset, attitude, competences, concepts, and tools are relevant in preparing future architects and urban designers for a role as agents of change?

Traditionally, mobility has been understood primarily in terms of accessibility. The aim of infrastructure, like transport networks and hubs, and the optimization of its flows, essentially is to move people from point A to point B. This understanding is often framed through engineering and logistical lenses, positioning mobility as a functional aspect facilitated by infrastructure, and indirectly by its architectural and engineering design, which shapes it. From this perspective, mobility manifests architecturally through stations and related buildings that serve as nodes of integration with connotations, such as landmark, commercial, domestic, cathedral, transfer, catalyser, public space, technology, or memory.

The growing demand for mobility occupies a significant place on policymakers' agendas across metropolitan Europe. Station projects have emerged as critical components within urban scenarios, acting as catalysts for development in metropolitan areas. However, policymakers and designers must grapple with the complexity inherent in station projects, which arises from multiple factors: the diversity of stakeholders and their varying ambitions and expectations; fluctuating financial, economic, and political conditions; and the specific urban contexts of station locations, which require balancing infrastructural necessities with architectural and urban design interventions.

Historically, radical transformations in railway infrastructure have profoundly influenced European urban development. Railway corridors have been interpreted not merely as transportation conduits but as catalysts for urban growth and regeneration (ProRail, 1999). In the latter half of the 20th century, train stations were increasingly embedded within broader urban visions, serving as focal points for business opportunities at strategic city locations. In some cases, particularly in the United States, these developments have redefined the meaning and role of station buildings. For example, the original Pennsylvania Station in New York City, completed in 1911, was celebrated as a Beaux-Arts masterpiece and architectural landmark. Today, while Penn Station remains one of the busiest passenger facilities in North America, it is largely hidden beneath the commercial complex of Madison Square Garden, symbolizing changing urban priorities (Ross, 2000).

With the advent of high-speed rail (HSR) in Europe, many cities leveraged these metropolitan-scale railway networks to stimulate new urban developments. Examples include the Euralille and Grand Paris Express projects in France and the 'Nieuwe Sleutelprojecten' (NSP) in the Netherlands (see left and Figures 1-2), both focused on redeveloping areas surrounding HSR or main stations in major cities. These projects often define stations as hubs, expanding the scope of urban intervention beyond the station building itself – a phenomenon evident in many European projects, such as Rotterdam Centraal (Triggianese, 2023). Architecture and urban design have become indispensable tools in urban renewal processes associated with HSR development. The arrival of high-speed rail has frequently coincided with comprehensive station redevelopment efforts, which, in turn, have spurred 'spin-off' architectural and urban interventions in surrounding districts. Cities such as Lille, Barcelona,



Figure 1. Den Haag Centraal station, designed by Benthem Crouwel Architekten. [© Jannes Linders]

Amsterdam, and Stuttgart exemplify this dynamic. However, since the 2008 financial crisis, many high-speed station area redevelopment projects in Europe have been postponed or scaled back. For instance, the Stuttgart 21 project experienced significant delays, while Barcelona's La Sagrera project saw its original ambitions substantially altered. These shifts provide an important opportunity for architectural and urban design research to critically reflect on the (re)development of stations and their surrounding areas, and to reassess their evolving role within broader urban development frameworks.

Stations as platforms for knowledge production

Station buildings carry multiple, layered meanings: they are sites of transit and technological infrastructure and complex environments where diverse knowledge domains intersect – such as flow analysis, user experience, and spatial dynamics. These spaces involve various actors, including designers, planners, policymakers, and users – all contributing to their evolving character.

Moreover, when considering mobility spaces for passengers – like train stations or airport terminals – there is an increasing convergence of property development, leisure activities, and public space design. The boundaries between public facilities and station interiors are becoming increasingly porous, as public spaces extend beyond the physical confines of the station building and vice versa. This blending creates a novel and emerging field of investigation. However, under the influence of commercial interests, the interior, 'public spaces' of transport hubs have become selective and often privatized. The introduction of retail, dining, and entertainment functions attracts and engages visitors, thereby granting these interiors a quasi-public character. This dynamic

enables the station interior to catalyse immediate circulation and activate adjacent streetscapes and even entire neighbourhoods. This phenomenon represents a significant shift in how stations contribute to urban life, a shift that must be thoroughly understood by city planners, stakeholders involved in station development, and the designers themselves. Key questions arise in this context: who owns and manages the spaces in and around stations? How can design contribute to defining the station as a public and urban space amid the diverse interests of multiple actors?

In this regard, stations increasingly function as platforms for collective knowledge production, where design, social science, data analysis, and policy intersect and inform one another. At TU Delft, the Complex Projects studio in the track Architecture of the MSc programme Architecture, Urbanism and the Building Sciences employs station projects as cases to address integrated design-thinking. They enable students and researchers to explore how architecture can operate across multiple scales and sectors, fostering an understanding of integrated design approaches and methodologies that respond to the complex realities of contemporary mobility infrastructures.

The role of design in station projects

The argument presented in this contribution is based on several key findings from research studies on station area development:

- Station area development projects typically lead to the formation of partnerships and joint efforts between public authorities and private developers, focused on interventions at both the district and building levels.
- The definition of station projects – particularly in the pre-design phase – emerges through a collaborative process involving clients, policy advisors, planners, developers, architects, and various designers.
- The planning and design of station projects – encompassing the station building(s) and its surrounding urban district – require the involvement of various disciplinary fields, ranging from infrastructural and transport planning and design to area development, master planning, urban design, and architecture.

This raises a critical question: What role does design play in the early definition phase of station projects? At TU Delft and elsewhere (Van Acker & Triggianese, 2021), several research initiatives have examined station development processes from planning, governance, and technical perspectives. For example: Gert-Joost Peek and Sebastian Rizal have explored the project management aspects of station projects (Peek, 2006; Rizal, 2007); Sebastiaan de Wilde, Jacob Trip, and Peter Pol have focused on the relationship between stations, railway networks, and urban development from a planning and policy perspective (De Wilde, 2006; Trip, 2007; Pol, 2002); Paul Chorus has studied transit-oriented development (TOD) – originally developed in the United States – and its application in Tokyo and the Dutch Randstad (Chorus, 2012). From an architectural and urban design perspective, Roberto Cavallo has investigated the historical relationship between Dutch city development and railway infrastructure construction (Cavallo, 2008). Ana Martins da Conceição has undertaken a comparative study of European station areas, analysing integrated spatial approaches to their (re)development (Martins da Conceição, 2014). [Transit-Oriented Development, page 114] [Train Station Design, page 308]

While this growing body of research addresses a wide range of issues related to stations and their urban contexts, a specific focus on the strategic role of design in the early stages of station and city development remains underexplored. There is limited research on how integrated design approaches – involving multiple actors and disciplines – can contribute meaningfully during the formative phases of station projects. This gap represents a valuable opportunity for further architecture and urban design research. [Integrated Infrastructure Design Method, page 290]



Figure 2. Rotterdam Centraal station within a high-density, mixed urban area as one of the six Dutch key projects for station renewal. [© Jannes Linders]

Another critical challenge lies in the initiative phase of station area redevelopment. A lack of experience, unclear design briefs, and ambiguous project objectives often mark this early phase. Political negotiations dominate the agenda as stakeholders attempt to align different visions and ambitions. Without a clearly defined design framework or shared understanding of goals, these processes frequently suffer from miscommunication, leading to inefficiencies, cost overruns, and conflict in subsequent design, construction, and operation phases. There is thus a pressing need for research that clarifies and articulates the role of architectural and urban design knowledge in the early, strategic stages of station area development. A better understanding of how design operates not just as a product but as a negotiation, visioning, and integration process can help improve outcomes in complex, multi-stakeholder projects. In this respect, advancing theoretical and applied insights into the role of design in station projects can make a meaningful contribution to academic scholarship and professional practice. [Stakeholder Analysis, page 112] [Research by Design Framework, page 108]

Intermodal nodes in a complex political, social, and organizational context

The development of train stations, particularly in dense urban environments, is often hampered by fragmented governance structures and competing stakeholder agendas. For example, in the Dutch context, the responsibilities are divided among four primary groups: governmental agencies, railway organizations, public and/or private developers, and users. Key institutional actors include: ProRail as infrastructure provider of the Dutch government responsible for rail and station infrastructure, Dutch Railways (Nederlandse Spoorwegen - NS) as operator and owner of station buildings, and local municipal governments for the urban area. The involvement of multiple parties, with diverging interests, adds complexity to the design process.

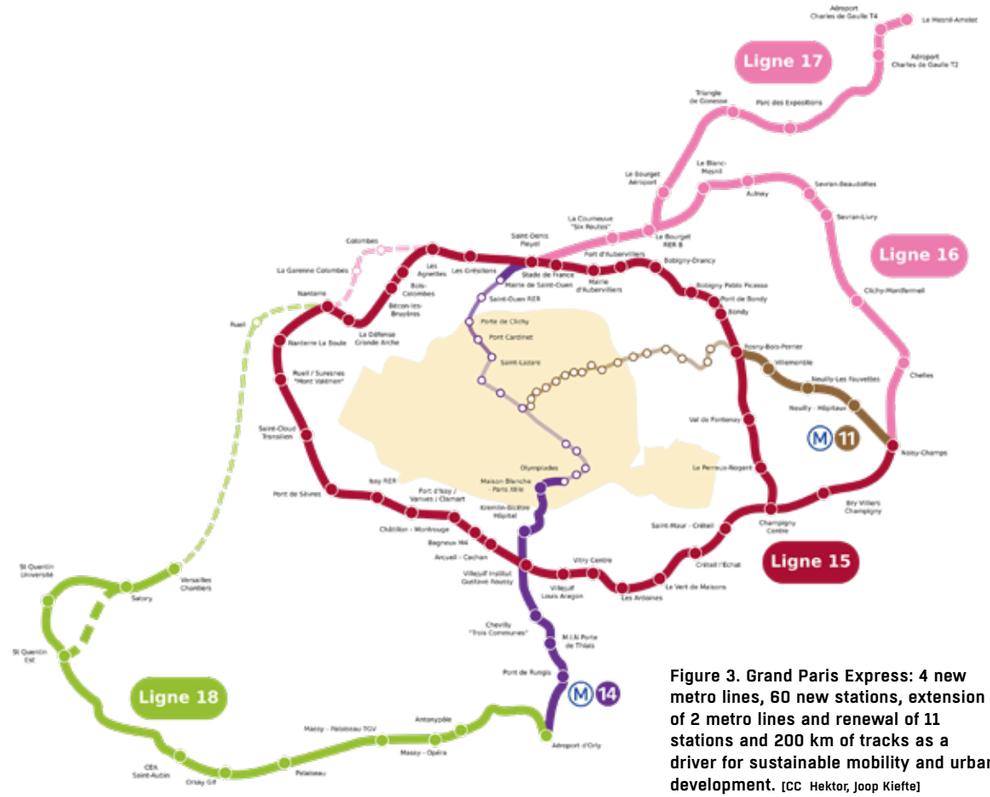


Figure 3. Grand Paris Express: 4 new metro lines, 60 new stations, extension of 2 metro lines and renewal of 11 stations and 200 km of tracks as a driver for sustainable mobility and urban development. [CC Hektor, Joop Kiefte]

Designers in this context often face challenges in balancing short-term commercial interests with long-term maintenance, public value, and sustainability goals. This complexity increases significantly in projects involving high-speed rail, where development is characterised by market uncertainty, iterative design processes, and frequent revisions to spatial proposals. At the city scale, stations function as intermodal nodes, linking diverse urban areas while highlighting the possibilities and constraints of infrastructural and architectural design. Interactions with local stakeholders – from users to policymakers – also profoundly shape the outcomes of station projects, influencing whether they operate primarily as transport nodes or evolve into strategic urban catalysts.

European developments – France, notably, was the first country in Europe to invest in HSR infrastructure in the 1970s. Its TGV (Train à Grande Vitesse) network became a model for other nations. Within this context, the Euralille project exemplified how HSR infrastructure could be leveraged to enhance urban competitiveness (Triggianese, 2017). The redevelopment included upgrading the nearby Lille-Flandres station, constructing the new Lille Europe station (opened in 1994), and integrating intermodal facilities and public amenities – all designed to reposition Lille within national and international networks. As in Lille, other European cities used the advent of HSR as an opportunity to reinvent their station areas and urban image. In the Netherlands, stations such as Rotterdam Centraal have become powerful architectural and urban symbols (Figure 2). Reopened in 2014 and designed by Team CS, Rotterdam's new central station features an iconic roof structure and integrates multiple trans-



Figure 4. Grand Paris Express: metro station Saint-Denis – Pleyel, hub station for the lines 14, 15, 16 and 17. [CC Chabe01 / CC Chris93]

port modes within a vibrant public realm. Similarly, Madrid Puerta de Atocha, first opened in 1851 and transformed significantly in 1992 with the arrival of HSR, was reimagined by Rafael Moneo. His design incorporated a tropical garden into the former concourse, merging heritage preservation with modern functionality (Kaan & Triggianese, 2014).

Despite several waves of socio-economic and political change across Europe, HSR infrastructure development has continued to expand, albeit at varying speeds, accompanied by the emergence of a new generation of stations. These contemporary stations function as intermodal nodes, integrating multiple modes of transport (metro, tram, bus, bicycle, train) and combining them with diverse urban functions. They not only serve as transportation hubs but also as catalysts for urban regeneration and placemaking. A prominent example is the ongoing transformation of Gare du Nord in Paris. Initially opened in 1864 and extensively renovated between 1930 and 1960, the station continues to evolve in response to shifting urban and mobility demands. Following a decade-long renovation of the platforms, passenger building, and surrounding area, Gare du Nord underwent another major redevelopment ahead of the 2024 Olympic Games, with plans to triple its capacity to accommodate over 700,000 daily users. The French national railway company SNCF aimed to improve mobility performance and the quality of the surrounding public space. The project focused on facilitating multimodal flows inside and outside the station while regenerating the urban district better to serve passengers, visitors, and residents alike.

In parallel, the Grand Paris Express project represents a more systemic rethinking of urban mobility and spatial transformation (Figures 3–5). As one of Europe's most significant infrastructure projects, it involves the creation of four new automated and two extended metro lines and sixty new and eleven renewed stations across the Île-de-France region. Many of these stations are in suburban and peri-urban areas that have been historically underserved by public transport. Far from being mere transit nodes, the new stations are conceived as architectural landmarks, urban anchors, and agents of socio-economic revitalization. International design competitions – bringing together multidisciplinary teams of architects, planners, and engineers – emphasize spatial quality, accessibility, environmental sustainability, and user experience. The Grand Paris Express reinforces regional connectivity and aligns mobility development with broader goals of urban equity and decentralization. It is a paradigmatic case of how infrastructure-led urbanism can elevate peripheral areas into vibrant sub-centres within a polycentric metropolitan region.

Transformation has not been limited to major metropolitan stations. Increasing ridership and network extensions have also prompted the redevelopment of medium-sized stations. A notable example is Delft station in the Netherlands. Opened in 2015 and designed by Mecanoo and Benthem Crouwel, the station is a multifunctional complex combining municipal offices and intermodal facilities (train, tram, bus, bike). The project reconnected the historic inner city with surrounding

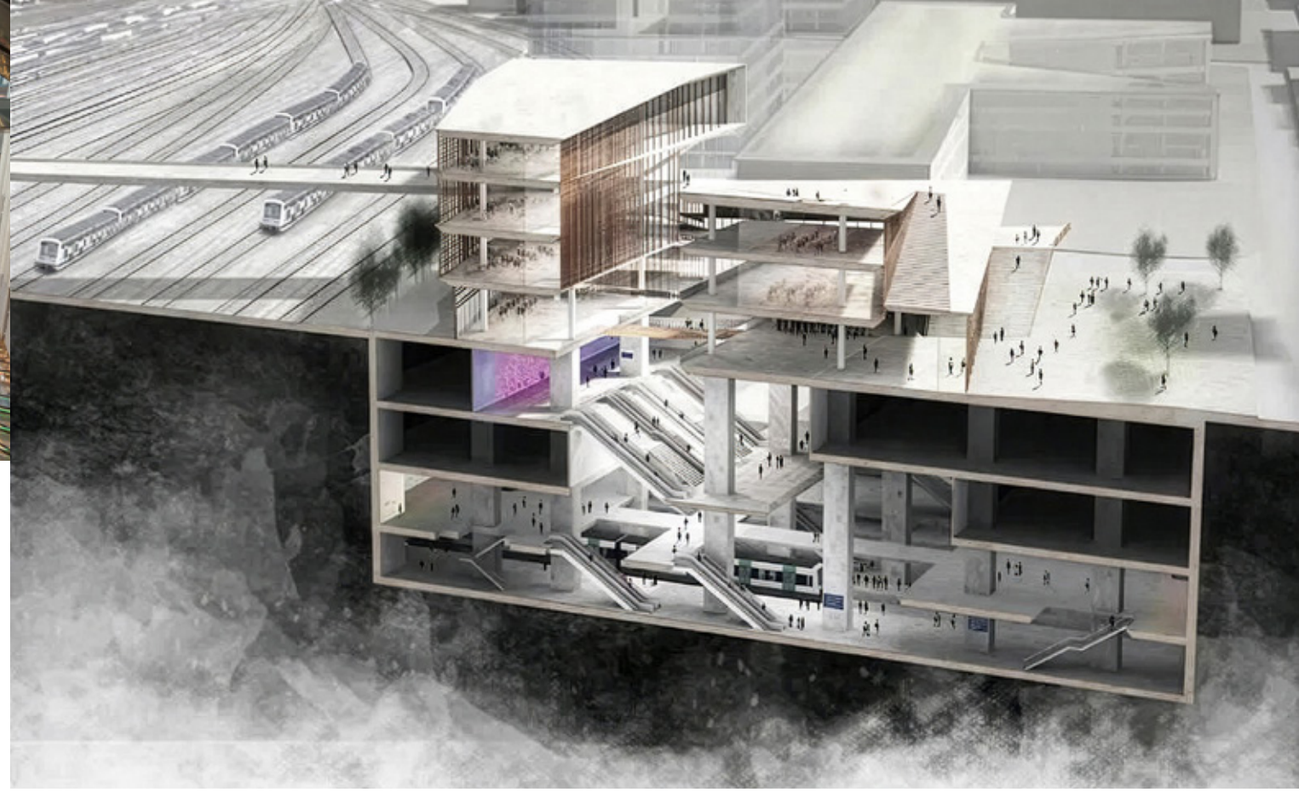


Figure 5. Grand Paris Express: metro hub station Saint-Denis – Pleyel, designed by Kengo Kuma & Associates. [© Kengo Kuma & Associates]

residential neighbourhoods (notably the 'Nieuw Delft' area) and encouraged urban regeneration. Area (re)development followed initially a 2003 master plan by Joan Busquets, although market changes over time have necessitated adjustments, leaving some parts of the redevelopment incomplete. Palmbout Urban Landscapes revised the master plan in 2013. [Bridging the Gap, page 30] [Spoorzone Delft, page 42]

Future prospects – Looking forward, train stations are expected to provide access to rail services and a broader ecosystem of traditional and emerging transport modes, including shared mobility solutions. They are evolving into intermodal hubs that contribute revenue to operators, integrate seamlessly with urban life, and serve as destinations in themselves. The Dutch government prioritizes sustainable mobility as central to the country's future resilience. It envisions a seamless transport system that prioritizes public and shared mobility and strongly focuses on the passenger experience. As cities densify around public transport nodes, peripheral stations are poised to transition from overlooked transit stops to sub-centres with emerging new station typologies. Within a polycentric metropolitan model, stations of various scales can function as densification points and gateways to low-car urban cores. These nodes have the potential to simultaneously support mobility transitions and add spatial value to the urban fabric. In this evolving European landscape, the Grand Paris Express is a flagship example of how infrastructure, urban planning, and architectural design can strategically align to shape inclusive, connected, and resilient metropolitan futures.

Walk-In: Impact on Nodes

How can we design attractive, people-centred stations that catalyse the mobility transition? What is the relationship between architectural design practice and mobility as a key driver of sustainable urban development?



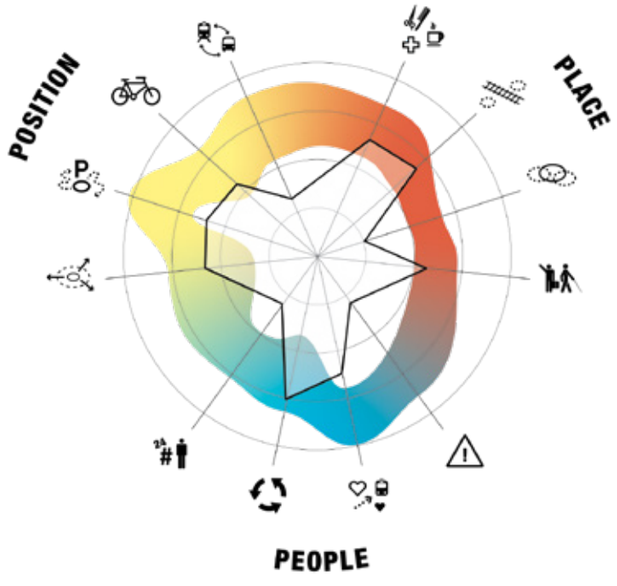


Figure 6. Walk-In, 3P Framework and Design Challenges and Strategies Deck: participants discussing the questions on the cards for the evaluation of the characteristic aspects of a station. The icons and scores are related to People, Place and Position.
[© Yagiz Soylev, Jakob Noren, Manuela Triggianese] / Images [© Emre Namli]



The 2022–2023 one-year research project *Walk-In* (Widening Sustainable Mobility Networks: Impact on Nodes), funded by the Dutch Research Council (NWO), aimed to bridge the gap between academic research and professional practice. Walk-In explored strategies for inclusive, multi-stakeholder design in station development, using small-scale suburban train and metro stations in Rotterdam South as test sites. The project investigated the strategic role of architectural design as a facilitator for stakeholder engagement in the design and decision-making processes surrounding node development. Specifically, it examined how stations could evolve from mere spaces of transit into vibrant, people-oriented places (GOCI.KIEM.01.045).

Walk-In adopted a collaborative, design-driven approach, engaging professionals, students, and researchers in co-creative processes to reimagine transit hubs. Taking the Dutch policy context, particularly Rotterdam's low-car inner-city strategy as its starting point, the study reflected on the role of suburban transit stations in supporting emerging mobility trends. It considered their potential to facilitate the shift from car to public transport and their dual function both as 'gates' to the city as well as 'hearts' or sub-centres with distinct spatial qualities within the metropolitan network. Metro station Slinge – currently operating as a park-and-ride gateway – served as the testbed for initial explorations. These investigations raised new questions that were addressed throughout the research process, supported by a series of tools and methods in analogue and digital formats. These included the serious gaming card deck 'Design of Hubs' about stakeholder negotiation, and a 'Conceptual Framework' (3P Framework), also in a format of discussion cards, showcasing best practices from the Dutch portfolio of station projects (Figures 6-7). Together, these tools enabled the analysis and (re) design of stations, facilitating the co-creation of architectural and urban visions that are inclusive, adaptable, and spatially attractive. [Design of Hubs-Game, page 88]

Central to the design toolkit are human-centred design principles and indicators that place users and their values at the forefront of planning and decision-making. The tools aim to foster empathy among participants, enabling them to engage with diverse stakeholder perspectives and simulate a negotiation environment where different forms of expertise and visions converge. Ultimately, Walk-In aimed to advance a multidisciplinary co-creation methodology for designing stations prioritizing human and social values. It sought to maximize the transformative potential of suburban station areas, making them meaningful, sustainable, and community-oriented components of metropolitan regions.

A design-value approach applying the toolkit to transit stations – Transit hubs in suburban areas face a dual challenge: they must be effectively integrated into their urban surroundings to serve as catalysts for redevelopment, while also accommodating the diverse agendas of stakeholders, addressing user needs, and complying with environmental regulations. Designing such hubs is a complex endeavour in real-world and educational settings due to the multi-layered urban fabric and the multitude of disciplines and stakeholder interests involved. Architectural design is an active tool to address these challenges by creating, testing, and critically discussing strategic interventions and decision-making processes. Specifically, it reorients the focus of *architectural design for mobility* toward user experience and the qualitative dimensions of mobility within the built environment surrounding public transport stations as transit hubs. To support this approach, the toolkit comprises two complementary tools based on decks of cards (see figures):

1. *Conceptual Framework (3P Framework):* this framework emphasizes three core values for the (re)design of public transport stations:

   - *People's* experience of mobility, addressing the human need to move from point A to B;
   - *Place*, highlighting the spatial quality of the transit environment;
   - *Position* within the broader mobility network, focusing on its accessibility and nodal role.

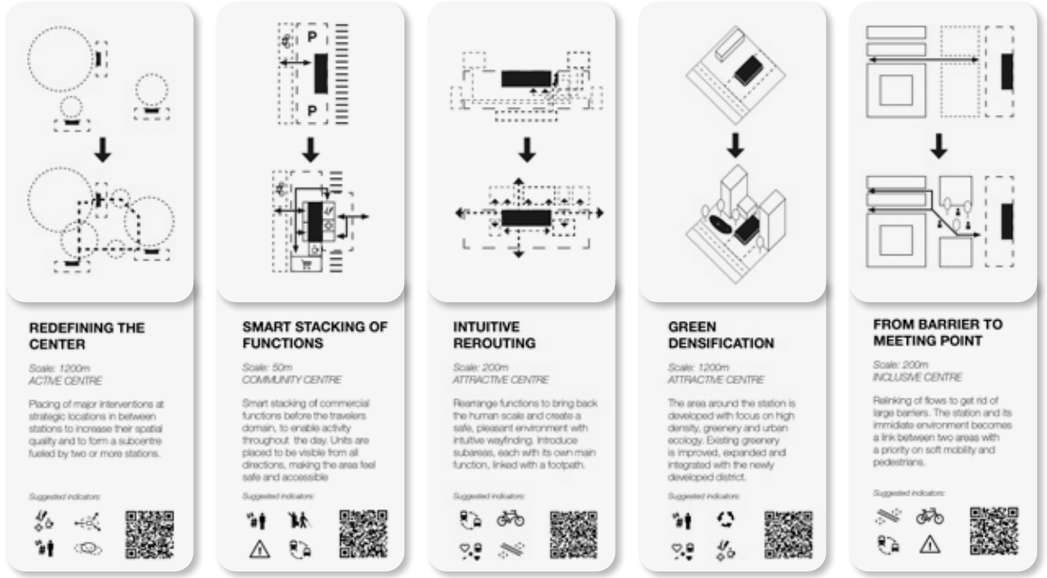
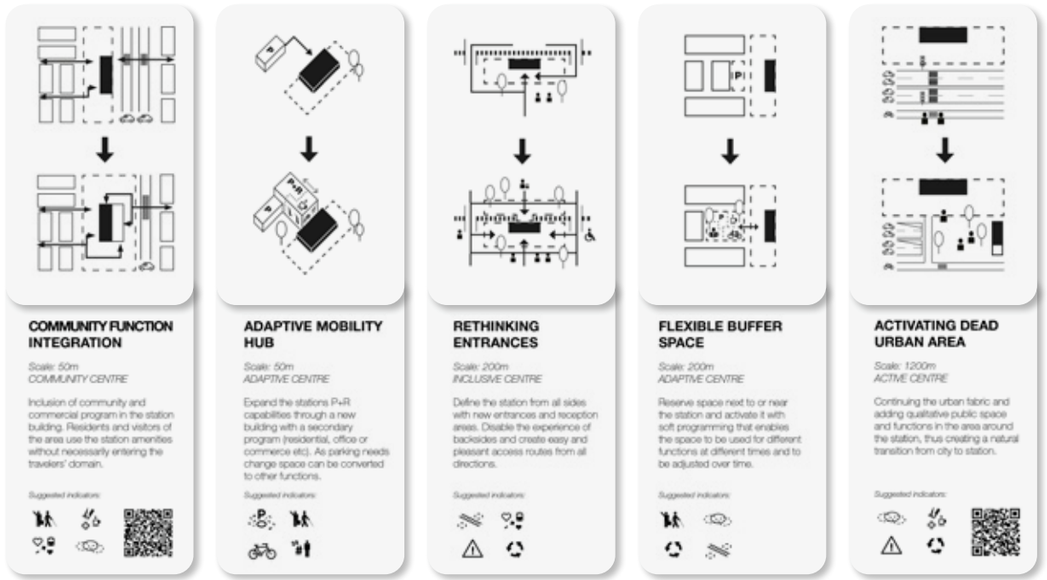


Figure 7. Walk-In, Design Challenges and Strategies Deck: these cards contain design strategies for the challenges of a specific aspect. The strategies were discussed with experts on station design. The Walk-In deck of cards has been conceptualized by researcher Yagiz Soylev, student assistant Jakob Noren and author of this contribution. [© Yagiz Soylev, Jakob Noren, Manuela Triggianese]
Each card shows, from top to bottom: a diagrammatic example of the implemented design suggestion, which can be used to better comprehend the suggested design solution through visualisation. / Middle: brief discription of the design suggestion, used to gain a better understanding of how the design solution can be implemented and what its impact will be. / Bottom: indicators and QR code displaying which indicators will be affected, which can be used to assess which design solution will benefit the future station profile and to gain more information about real-life example projects of the partners related to the design solution.



These dimensions serve as guiding principles for understanding and enhancing the qualitative experience of mobility.

2. *Design Challenges and Strategies Deck:* this card deck presents design challenges, each with associated strategies and clear objectives. The strategies aim to transform stations into inclusive, community-oriented, active, adaptive, and attractive centres. These best practices are derived from the work of Dutch designers participating in the project.

Together, these tools facilitate user-centred dialogue in the design of stations and their surrounding areas. Participants employ the cards to explore multiple approaches to a single problem, compare the effectiveness of various strategies, and envision diverse development trajectories based on stakeholder perspectives. By the conclusion of the process, participants are expected to identify the primary design challenge for a specific site and formulate an appropriate design strategy. The ultimate goal is to enhance collaborative decision-making and foster innovative, context-sensitive solutions in transit-oriented development. Interactive working methods – such as periodic review meetings, collaborative workshops, and iterative discussions on diverse design proposals – serve as critical processes in fostering support and consensus. They challenge rigid role definitions, encourage creative engagement, and allow designers to explore their evolving responsibilities within a network of stakeholders. Ultimately, such settings offer a valuable opportunity to redefine the designer's role early in the project, positioning them as a mediator and innovator within increasingly complex development environments.

Beyond the project brief: Evolving roles, approaches, and tools for designers

In both academic and professional research contexts, current projects and critical reflections examine the evolving role of design in shaping project briefs, assessing impacts on the urban environment, and navigating the influences and responsibilities of public and private stakeholders. These investigations also explore the project process and the collaboration modalities among all involved parties. Typically, design proposals begin as conceptual sketches within development processes and progressively gain detail as the project advances toward greater certainty, ultimately culminating in documentation sufficient for construction. In the case of complex interventions – often characterised by long-term horizons, multiple ambitions, and a diverse array of clients – the involvement of the architect or urban designer is particularly critical. Designers play a central role in facilitating information exchange, identifying, and articulating issues, formulating shared visions, and translating these visions into spatial strategies (Carmona, 2021). The design process contributes significantly to formulating the project brief, establishing the scope, and identifying opportunities for future planning and redevelopment, particularly in contexts such as station areas and surrounding urban environments. Briefing is a dynamic and iterative process in which clients and users make decisions which are then communicated to the design team (Blyth & Worthington, 2010). This process requires continuous dialogue between users and designers, bringing different expectations and perspectives. Architects and urban designers must be adept at facilitating discussions among all stakeholders, seeking synergies across disciplines, and managing the interplay of various design tools. Design, in this context, becomes both a strategic and communicative instrument. It is shaped through collective dialogue during design team meetings, where information and ideas are exchanged via sketches, photographs, physical models, reference literature, and site visits. These methods support informed decision-making and foster a shared understanding among all participants.

The interplays between public and private investments are increasingly significant, reflecting a broader societal demand for innovative initiatives that address complex and evolving needs. Public-private partnerships (PPPs) have emerged as a response to these challenges, emphasizing

the necessity for collaborative approaches grounded in recognizing high and diverse societal expectations. Coordinating multiple investments within projects spanning twenty to thirty years presents substantial challenges, necessitating innovative financing mechanisms and novel modes of collaboration. These new approaches inevitably influence conventional design and construction practices. Designers are now required to engage with a wide range of stakeholders within unstable and often shifting programmatic frameworks, which can lead to inefficiencies and designs misaligned with project objectives.

Consequently, integrating the concept of the life cycle into architectural thinking becomes essential to the contemporary design process. Design must serve multiple roles throughout the development of a project: not only as a means of visual communication that provides a compelling vision of the future, but also as a framework that accommodates ambiguity regarding the precise outcomes and forms of development. Effective design should be visually specific and conceptually flexible, capable of adapting to stakeholder input and changing conditions. [Life Cycle Management, page 98]

This contribution emphasizes the importance of repositioning design within a multidisciplinary context, particularly in complex, large-scale initiatives such as station area development. Designers – whether architects, planners, or engineers – must operate at the intersection of various domains, including architectural design, urban planning, infrastructure engineering, and project management. Their role is increasingly strategic, facilitating the alignment of interests among users (space occupants), developers (space providers), and public authorities (space regulators).

Manuela Triggianese, TU Delft

REFERENCES: Blyth, A., & Worthington, J. (2010). *Managing the brief for better design* (2nd ed.). Routledge ■ Carmona, M. (2021). *Public places, urban spaces: The dimensions of urban design* (3rd ed.). Architectural Press ■ Cavallo, R. (2008). *Railways in the urban context: an architectural discourse.* Doctoral dissertation. Delft University of Technology ■ Chorus, P. (2012). *Station area developments in Tokyo and what the Randstad can learn from them.* Doctoral dissertation. University of Amsterdam ■ De Wilde, Th. S. (2006). *Rail estate, multiple use of space, and railway infrastructure.* Doctoral dissertation. Delft University of Technology ■ Kaan, C. H. F., & Triggianese, M. (2014). Negotiating new centralities. In M. Gausa & M. Ricci (Eds.), *MED.NET.REP.02*, 86–93. LISt Lab Laboratorio Internazionale Editoriale ■ Martins da Conceição, A. (2014). *From city's station to station city: An integrative spatial approach to the (re)development of station areas.* Doctoral dissertation. Delft University of Technology ■ Peek, G. J. (2006). *Locatiesynergie: Een participatieve start van de herontwikkeling van binnenstedelijke stationslocaties.* Doctoral dissertation. Delft University of Technology ■ Pol, P. M. J. (2002). *A renaissance of stations, railways, and cities: Economic effects, development strategies and organisational issues of European high-speed-train stations.* Doctoral dissertation. Delft University of Technology, DUP Science (TRAIL Thesis Series) ■ ProRail. (1999). *Infrastructuur als katalysator.* ProRail ■ Rizal, S. (2007). *Managing collaborative design.* Eburon Uitgeverij B.V. ■ Ross, J. (2000). *Railway stations: Planning, design, and management.* Architectural Press ■ Triggianese, M. (2017). Euralille, twenty years on. *OverHolland, 16/17,* 111–139 ■ Triggianese, M. (2023). Design of co-creation in Rotterdam Central Station (1996–2007): Architecture and urban design roles in the multi-stakeholder collaboration. *SPOOL, 10*(1), *57-72* ■ Trip, J. J. (2007). *What makes a city? Planning for quality of place: The case of high-speed train station area redevelopment.* Doctoral dissertation. OTB Research Institute for Housing, Urban and Mobility Studies, Delft Centre for Sustainable Urban Areas ■ Van Acker, M., & Triggianese, M. (2021). The spatial impact of train stations on small and medium-sized European cities and their contemporary urban design challenges. *Journal of Urban Design, 26*(1), 38–58 ■ WALK-IN (acronym): Widening sustAinable mobiLit networKs: Impact on Nodes, NWO KIEM GoCI 2020–2023 [GOCI.KIEM.01.045].

LESSONS

WHY STATIONS MATTER IN THE ARCHITECTURE DISCOURS

When looking at the developments in practice and academia in the last decades, it is clear that a paradigm shift is ongoing in thinking of the role of stations in the context of sustainable mobility and urban (re)development. New theoretical notions, concepts, methods, and techniques are developed to reach a growing community of designers and the next generation of designers. Both practice and education must collaborate closely to find a synergy in the further production, exchange, and application of knowledge and experience. The following lessons may be drawn.

- ***Repositioning designers and stations within the field 'architecture of mobility'.***
Within architecture and urban studies, the roles of both designers and stakeholders are increasingly recognized as active agents in shaping a sustainable built environment. Engaging with complex urban and infrastructural processes, designers require anticipatory, systemic, and user-centred approaches. They mediate between competing environmental, technical, political, and social interests while crafting environments adaptable to ongoing change.

- ***Rethinking the design process for stations as mobility hubs interwoven in the urban fabric and part of the present and future daily life of many.***
Stations are no longer conceived merely as infrastructural nodes within transport networks. Instead, they function as urban condensers: places where people, information, and capital flow converge. As mobility hubs, stations enable intermodal connections and shape their surroundings' spatial and social dynamics. This evolving landscape necessitates a rethinking of the design process itself. Rather than responding to predetermined briefs, designers engage in iterative and speculative practices, prioritizing participatory processes, communication techniques, and systems thinking. In this context, the station becomes both a spatial artifact and an object of study, serving as a collaborative platform to explore integrated design and the future of our cities.



FEATURED DESIGN: STATION ASSEN

GATEWAY TO THE CITY

In the last two decades the so-called Nationale Sleutelprojecten (NSP) were realised in the Netherlands for a renewal of six train stations, including the central stations of Rotterdam, Utrecht, and The Hague. This happened not only for capacity reasons, but also as driving force for urban development and renewal. What about cities like Assen, the provincial capital of Drenthe? How can infrastructure, urban, and architectural design become symbiotic forces?

Characteristics

The new Assen station building is the key intervention in the area development, enhancing accessibility and promoting growth for the city of Assen, as part of the FlorijnAs urban development programme. The ensemble of brick, wood and glass reflects the character of the Drenthe's capital and offers a new gateway to the city.

A range of mobility interventions around the station square have reshaped the area into a pedestrian-friendly, green urban space with minimal car impact. It includes a new underground pedestrian passage, a shortened and restored bicycle tunnel, a car tunnel, and an underground bicycle parking facility for 2,600 bicycles.

At the heart of the design is a 3,000 m^2 triangular roof constructed entirely of wood, the first roof in the Netherlands to bridge railway tracks using this material. With sides measuring 78, 88, and 90 metres and reaching a height of 10 metres, the roof appears to float above the station. Its gentle slope at the bicycle entrance and its curved form over the tracks result in a sculptural, context-responsive structure. Skylights positioned at the roof's centre allow daylight to animate both the platforms and the station hall, and to contribute to feelings of safety. The use of wood reflects commitment to sustainability and aligns with the green character of Assen. Sedum planted along the roof edges supports rainwater management. For durability and contrast, the columns and roof edges are clad in champagne-coloured coated metal, harmonising with the natural timber. Freestanding columns offer flexibility for future adaptations to passenger flow or commercial needs.

Detached brick buildings beneath the roof house the station and commercial functions. Their rounded corners and purple-red facing bricks complement the red carpet of brick pavers and the red porphyry station floor. The design ensures an open, welcoming station that balances clarity with warmth. The logical organisation of the interior public space supports efficient passenger movement.

Significance

The urban plan for the station area is in line with the FlorijnAs master plan, reinforcing the north-south axis of Assen, also developed by De Zwarte Hond architects. The ambition was to improve accessibility for residents and visitors by foot, bicycle, or car, while bridging a city historically divided by the railway tracks. The design eliminates visual and physical divisions, reconnecting neighbourhoods and reinforces a strong civic identity grounded in openness, accessibility, and unity. The station's triangular roof serves as the structural and symbolic backbone of the entire area, anchoring a range of functions and uniting city districts, while offering a gateway to the city. As a landmark, it enhances orientation for pedestrians and cyclists, and identity within the urban landscape.

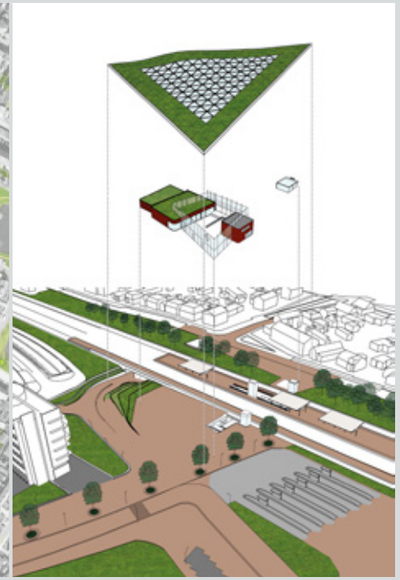
Previous pages: Assen station, gateway to the city and connecting link between the centre and residential areas.
[© De Zwarte Hond, Egbert de Boer]





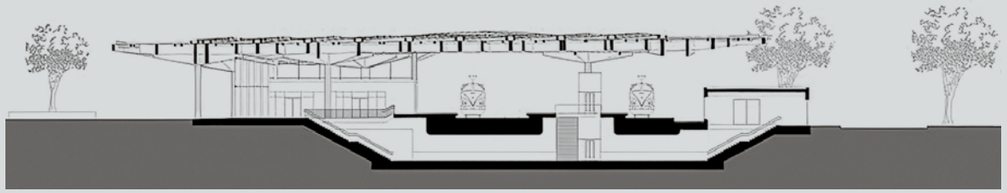
Station square with the first station in Assen, in use from 1870 until around 1935-1940. Designed by Karel van Brederode. [PD Het Utrechts Archief] **/ The second station of Assen, built in 1989. Designed by Rob Steenhuis.** [© De Zwarte Hond]





The station and square are part of the urban development FlorijnAs and are connected to the city center. Through car traffic goes through a tunnel under the station square / Cross-section with roof, platforms, facilities, pedestrian underpass, bicycle parking and access on two sides. [© De Zwarte Hond]





Technical cross-section of the structural components of the station. [© De Zwarte Hond]

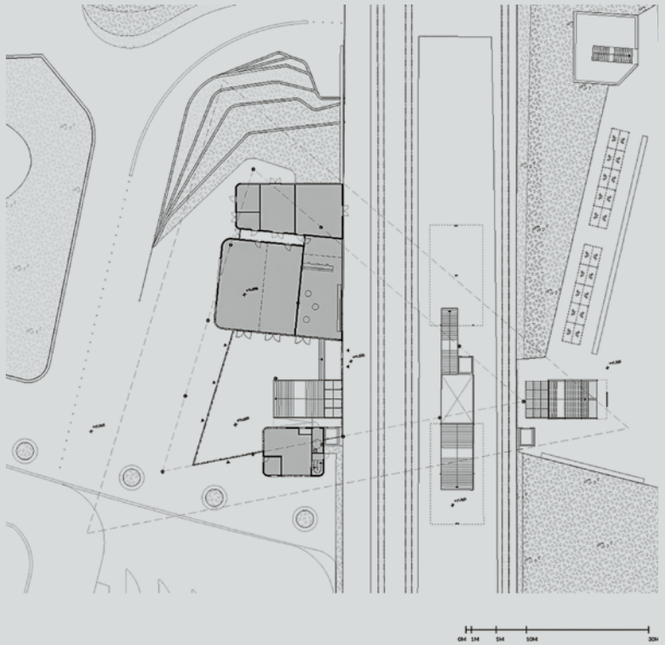
The inclusion of the car tunnel beneath the station square enabled the transformation of the surrounding area into a traffic-calmed, public space. Today, the integrated design of the station acts as a plaza with routes to the city center and neighbourhoods. It invites people to gather, pass through, or stay – reinforcing spatial quality, greenery, and pedestrian experience, all this at a human scale, as defines this area of the city.

The station received the public award for the best building from the Dutch architect association BNA in 2021, as well as the international The Plan Award in 2022, and was nominated for the Prix Versailles 2022 in the category passenger stations.

Jochem van Berne, De Zwarte Hond

LOCATION: Assen, Drenthe ■ **CLIENT:** Dutch Railways (NS), ProRail, Municipality of Assen ■ **ARCHITECTURE:** De Zwarte Hond, Powerhouse Company ■ **URBAN DESIGN:** De Zwarte Hond ■ **ENGINEERING:** Breed Integrated Design, Munnik Brandadvies, InVra plus, Miebach Ingenieursburo ■ **CONSTRUCTION:** Hegeman Bouw & Infra, Heko Spanten, Broeze, Licotec ■ **REALIZATION PERIOD:** 2014–2020.

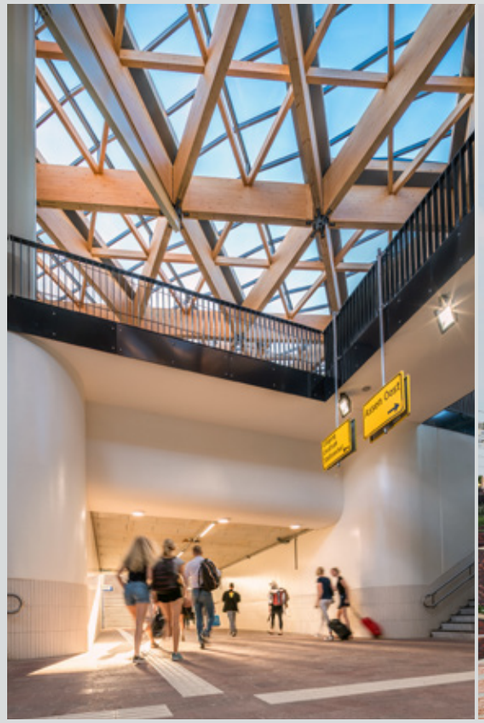
FURTHER READING ■ Gemeente Assen (2011). *FlorijnAs. Structuurvisie – ontwerp.* Gemeente Assen ■ Grontmij Nederland B.V. (2011). *FlorijnAs & Park Diepstroeten. Plan MER.* Grontmij Nederland B.V.



Floor plan of the station and the spaces for the station and commercial functions. [© De Zwarte Hond]



View from the platforms with the translucent wooden roof construction. / Passenger underpass. /Through route with cyclist and pedestrian tunnel under the railway. [© De Zwarte Hond, Sebastian van Damme, Egbert de Boer (below-left)]





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Casco Concept

For a long time, human-made interventions in delta systems have created conditions for urban settlement and economy and its ever-ongoing growth. This often comes at the expense of nature and its ecological processes. How to reconciliate human activities within a natural environment in a balanced way? The casco concept offers a clue to this.

PURPOSE – The casco concept is a design concept for riverine systems in which spatial quality is secured by creating a framework of low dynamic functions within an area for the long term. It proposes a conscious reciprocal spatial relation between this framework and the adjacent user space. The framework is where sustainability ambitions and spatial qualities are secured over a long timeframe. It provides robust base conditions as well as sufficient space to support the overall ecological workings of a given landscape. The user space consists of user functions and can develop independently and flexibly because of the robust nature of the framework. Depending on landscape typology and local conditions, the framework and user space can take on different shapes, sizes and uses, while the materialization depends on the specific context. The framework can not only support navigation, but also ambitions for urban nature that offer a robust basis for the overall spatial design.

The casco concept was developed in the late 1980s and early 1990s and was inspired by the so-called plan 'Ooievaar' (De Bruin et al., 1987). This plan proposed a strategic spatial relation between natural and agricultural areas in the Dutch river delta in order to reactivate and to prioritise biodiversity processes of the riverine landscape. The main observation was that the abiotic and biotic layers of the landscape develop much slower than the cultural and urban layer. The latter is subject to human-led economic and societal trends and has a higher degree of uncertainty. The casco concept is the design counterpart of the layer approach, a planning concept that recognizes the differences in dynamics of layers: slowly developing processes (nature, soil, groundwater reservoirs), networks and infrastructure that organise the landscape by humans on the larger scale with a faster dynamic, and a top layer which consists of fast-developing human occupation (farmland and settlements/towns).

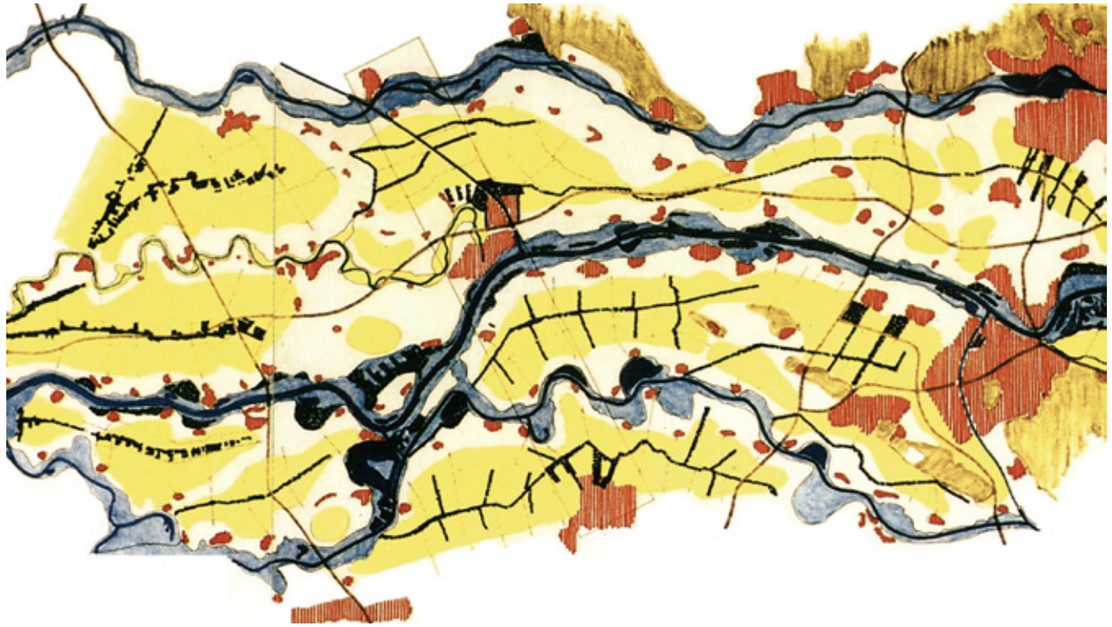
In a review of the casco concept – as part of the Redesigning Deltas project in 2023 – there was a 'negotiation space' as a spatial buffer was added to the concept, to acknowledge the potentials of synergy between the framework and the user space. For example, a buffer space can be a protected heritage landscape as part of the framework and can be used as user space for temporary water storage (H+N+S, 2023).

APPROACH – To make the casco concept operational for planning and design, the following steps must be taken:

1. *Define the framework:* identify – based on long-term ambitions – the slow natural- or human-made protected heritage, functions, and ecological processes within an area. Which amount of space is needed under different climatological conditions, now and in the future? To what extent is the framework itself in use for navigation or ecosystem services? Which 'hard' infrastructure encloses the functions and processes?

APPLICATION
Urban or landscape design and decision-making for sustainable development at different scales. It can be used for systematic managing of dynamic processes, dealing with uncertainty, and improving resiliency because of the relation between the framework, the negotiation, and the user space functions. It supports to goal integration in interdisciplinary design by disciplinary experts and sectoral stakeholders.

LIMITATIONS
When the determination of the framework, negotiation and user space becomes dispersed, it can become difficult to organise an inter-disciplinary approach.



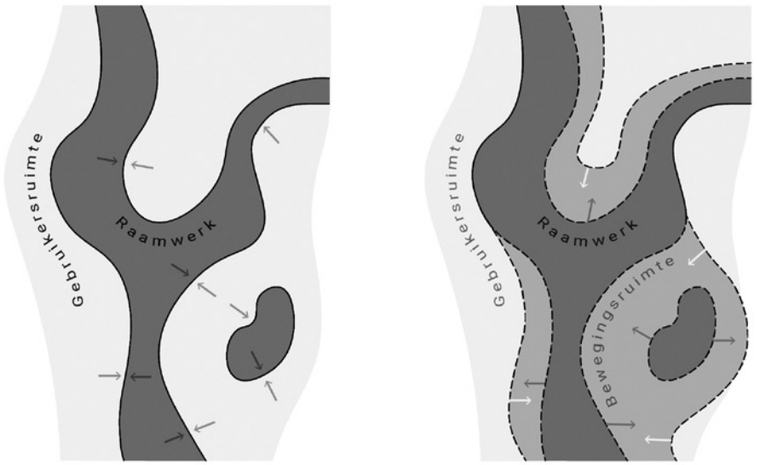
Plan 'Ooievaar' (Stork): an archetypical illustration of the casco concept which distinguishes the river and its 'confrontation' with the embankments and lower-lying areas within the landscape structure. It proposed that a separation was needed and that this should be interwoven if possibly. The name of the plan refers to the return of the black stork, expressing the recovery of natural conditions (De Bruin et al., 1987). The plan was highly influential in Dutch policies and strategies for the environment like the 'Room for the River' programme / The Waal bridge near Nijmegen: relocation of the dike at the Waal River for the creation of the city island and bypass channel at Lent. [© Rijkswaterstaat, Ruben Smit]



2. *Define the user space:* identify the economic and social functions and activities within an area. Which amount of space is needed under different economic, social, and climatological conditions, now and in the future? In which way and to what extent do the user functions and activities depend on the framework and its functions and processes?
3. *Define a negotiation space:* identify to what extent and under which conditions the space needed for the framework and user functions should be separated. To what extent does infrastructure facilitate or block the 'negotiation' between functions? How much buffer space is needed and for what kind of period? Can the buffer space be of use for other specific functions or processes?

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FURTHER READING ■ De Bruin, D., Hamhuis, D., Van Nieuwenhuijze, L., Overmars, W., Sijmons, D., & Vera, F. (1987). *Ooievaar, de toekomst van het rivierengebied.* Stichting Gelderse milieufederatie ■ Hartmeyer, L., Kaletkina, A., Iuorio, L., & Hooimeijer, F. (2024). The Casco concept as an enabler for interdisciplinary design: Designing with flood risk in Venice, Italy. *Journal of Urbanism.* 2424531 ■ H+N+S Landschapsarchitecten. (2023). *De lagenbenadering, het lagenmodel en het casco concept. Reflecties op drie instrumenten in het herontwerpen van de Nederlandse delta.* H+N+S Landschapsarchitecten.



The left drawing shows a river as the framework space (Raamwerk) and the user space (Gebruikersruimte), in many situations used for agriculture. The right drawing shows the buffer space (Bewegingsruimte) which expresses interwovenness between the separated spaces and its functions. [© H+N+S Landschapsarchitecten]



The bypass of the Waal River at Lent, Nijmegen, which aims to reduce the water level in winter and offers recreational use in summer at lower water levels. [© Rijkswaterstaat, Johan Roerink] / Excavation at the IJssel River for floodplains and nature near the city of Arnhem. [© Rijkswaterstaat, Room for the River] / Port of Tholen at the Volkerrak Zoommeer in Zeeland: water storage during the period when flood defences on the coast are closed and there is excess water from the rivers; also suitable for recreational use. [© Rijkswaterstaat, Room for the River]





Environmental Indicator

Sustainability is related to natural, social, human, and economic capitals and the way in which society and its successive generations deal with these, with our living environment serving as the physical foundation for them all. Transport and water infrastructure are therefore indispensable, but how can projects contribute to a more sustainable living environment? How can we get a grip on this broad concept that has so many facets?

PURPOSE – The environmental indicator (Omgevingswijzer) is a Dutch online tool to facilitate discussion about the sustainability and integration of an infrastructure or area development project along twelve sustainability themes (Rijkswaterstaat, 2025). It is clustered in social, ecological and economic sustainability themes as represented by the motto People, Planet and Profit. The approach is aimed at identifying risks and opportunities. It is one of the sustainability tools for the infrastructure sector developed by Rijkswaterstaat as executive organisation of the Ministry of Infrastructure and Water Management. The main ambition behind its promotion of sustainability and the availability of tools is to create more awareness within the sector and to stimulate its internalisation in organisations and processes and in the mindset of decision makers, planners and builders. In this way, projects will contribute to (inter)national sustainability goals like those of the United Nations (SDGs). In the Dutch context the environmental indicator relates to the notion of *broad prosperity,* which comprises material prosperity and well-being, health, environment, society, safety, work, education, and living (CBS, 2025).

The environmental indicator presents a graphical overview of the extent to which a project scores positive, neutral or negative on a particular sustainability theme (Figure 1). This is a qualitative judgement by involved experts and stakeholders on related sub-themes (Table 1). The tool could be customized for a project by leaving out or adding specific (sub)themes.

APPROACH – The environmental indicator is a process and communication tool within a stakeholder context which could be applied within the three stages for an integrated infrastructure design (Figure 2):

1. *Plan*: in this stage of a design assignment, the main concern will be explored and discussed to define the problems or challenges which should be addressed. The environmental indicator offers a systematic approach for identifying the present situation by involved experts and other stakeholders for the broad set of themes and sub-themes, in terms of omissions, existing qualities, risks, or opportunities from the perspectives involved. The scope could be narrowed down, if necessary or desired, to the relevant themes and sub-themes for the project. It creates awareness about the magnitude of the sustainability aspect and the need for integration for the project. It gives direction and scope to the project and clues for further investigation. For setting 'hard' and binding sustainability ambitions and objectives, another tool, the Ambition Web, is more suitable (CROW, 2024).

APPLICATION
The tool addresses infrastructure or area development projects at object and/or system level within their environmental context. To be effective as a cohesive framework on sustainability, a broad array of experts, disciplines and stakeholders is needed. This should be an integrated part of the project management during all stages, while the first stage is best suited for developing a shared vision and common mindset on sustainability and integration.

LIMITATIONS
The tool facilitates communication and agenda-setting and is no substitute for more specific tools and instruments during the various stages like a social cost-benefit analysis (SCBA), an environmental impact analysis (EIA) or multi-criteria analysis (MCA).

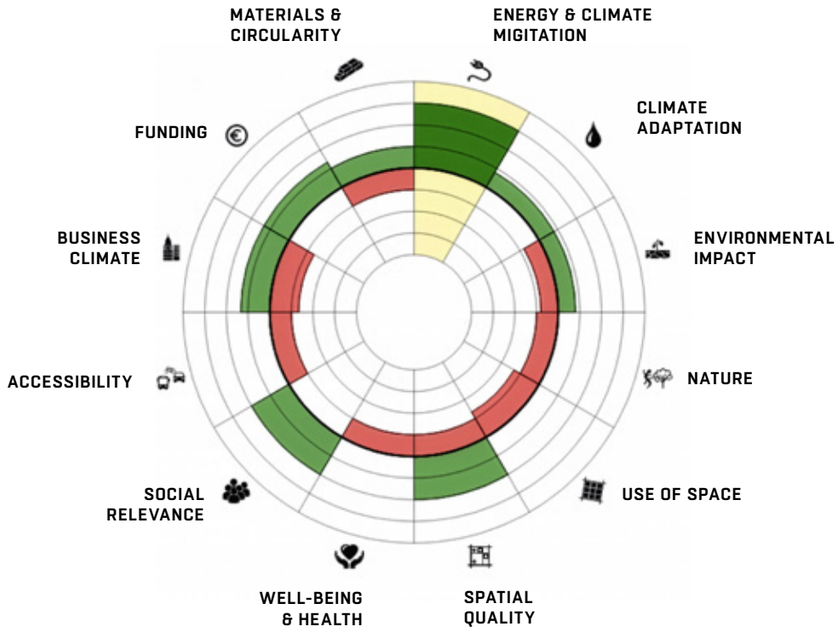


Figure 1. Overview of sustainability themes. Each segment of the diagram indicates if a sub-theme is positive (green), neutral or negative (red). [© Rijkswaterstaat] **/ Below: Table 1. Overview of sustainability themes and sub-themes.** [Source: Rijkswaterstaat]

	Theme	Subthemes
PEOPLE	social relevance	environmental participation, social return, sustainable deployment of employees within the construction chain of the infrastructure sector, local knowledge
	well-being & health	nuisance, health promotion (physical and mental), environmental safety
	spatial quality	experience value, use value, future value, social safety
	use of space	connection to regional developments, above-ground use of space, underground use of space (including cables and pipes), archaeology
PLANET	energy & climate mitigation	energy use (construction and use phase) and associated CO_2 emissions, energy generation, CO_2 sequestration, other greenhouse emissions
	climate adaptation	flooding, drought, heat, extreme weather
	environmental impact	water quality (prevention of contamination), soil quality (prevention or remediation of soil contamination), air quality
	nature	biodiversity, ecological structures
PROFIT	accessibility	accessible social and economic functions, accessible living environment, efficient use of infrastructure and sustainable mobility, road safety
	business climate	clusters, living and residential environment, knowledge infrastructure
	funding	life-cycle costs, social costs and benefits, future-proof investment, joint financing
	materials & circularity	prevention of the use of materials and raw materials, lifespan extension, closing the loop, sustainable and renewable materials

2. *Analyse*: the defined (sub)themes from the initial stage offer a guideline for specific analyses of certain (sub)themes which need a dedicated approach by experts. The individual (sub)themes function as lenses to investigate topics and to gain insight into the nature of risks and the way risks could be mitigated, and opportunities that could be developed.
3. *Synthesise*: once a vision, concept(s) and alternatives have been developed, the (sub)themes could be part of the evaluation to assess its performance on sustainability. This can be done qualitatively, in case no hard indicators and measures are available. The elaboration of the chosen alternative should lead to an integrated design that contributes to sustainability in multiple ways.

Hans de Boer, TU Delft

FURTHER READING ■ De Boer, H., Duinmayer, M., Gerretsen, P., Hinterleitner, J., Van der Wall, R., & Zonneveld, J. (2025). *Afslag meerwaarde. Tekenen en rekenen aan brede welvaart in stedelijke snelwegzones.* Kennis- en Innovatieplatform Stedelijke snelwegen & Ruimtelijke ontwikkeling ■ CBS. (2025). *Monitor Brede Welvaart en SDG's 2025.* CBS ■ CROW. (2024). *Ambitieweb duurzaamgww.* CROW ■ Hendrich, T., Euwals, R., & Thewissen, S. (2023). *Brede welvaart bij integrale gebiedsontwikkeling: vijf lessen.* Centraal Planbureau (CPB) ■ Rijkswaterstaat. (2025). *Omgevingswijzer.* Rijkswaterstaat. https://www.omgevingswijzer.org ■ Van Ruijven, K., & Tijm, J. (2023). *Leefbaarheidseffecten van integrale infrastructuurprojecten: inzichten uit onderzoek.* Centraal Planbureau (CPB).

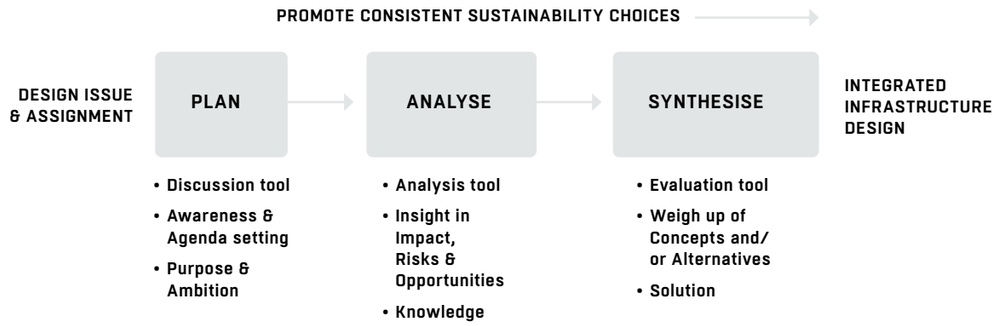


Figure 2. Application of the environmental indicator within the phases of integrated infrastructure design. (Hans de Boer)

Zaandam, North Holland: the junction of A7 and A8 bordering the Natura 2000 area Ilperveld, Varkensland, Oostzanerveld and Twiske, together forming the largest peat bog complex north of Amsterdam. This is a fragile location which raises questions related to environmental impact and nature but also to spatial quality. [© Rijkswaterstaat, Rob Poelenjee]



Integrated Infrastructure Design Lenses

The complexity of infrastructure development requires the effort of experts from many disciplines with their own methods, techniques and strategies. How to keep an eye on the bigger picture?

PURPOSE – The integrated infrastructure design lenses are a conceptual aid to point out and zoom in on certain aspects of an object, system, or environment. The lenses emphasize aspects that are dominant in the way disciplines and fields address design issues and assignments, and in their elaboration into a tangible and detailed design, like functionality for a civil engineer and spatial quality for a (landscape) architect. They give focus but at the same time they exclude other aspects, which can be problematic for problem definition, analysis, and concept creation. The application of (inter)related lenses can help students and professionals to be more aware about their own professional focus and those of other disciplines. This forms a basis for better mutual understanding and dialogue between disciplines in developing an integrated design that creates additional social value beyond only problem-solving (Figure 1 & Table 1). The idea of lenses originates from a discussion between leading scientists in the fields of architecture, landscape architecture, urban design, structural engineering, and infrastructure design and management. Central to the discussion was the separation, fragmentation and ongoing specialization of disciplinary fields and sectors, while infrastructure issues, design and the necessary collaboration become more complex. How to deal with these opposite directions and to reconcile design and engineering? One of answers was to introduce the lenses in design education so that students from various disciplines could became more aware of their own and others focus. (Riedijk et al., 2013).

APPROACH – As an aspect-related concept, the lenses can be of use in different phases of infrastructure development and can be combined with other methods, concepts or strategies.

- *Planning/initiation*: the phase of discussing challenges, problems, wishes and first ideas at client level, in which focus and scope must be figured out in terms of purpose, objectives and boundary conditions. What are the aspired values (e.g. performance, added value, spatial quality), what kind of solution is desired (e.g. functionality, intervention scales), who must be involved or who will be affected (e.g. collaboration) and why this solution (e.g. sustainability, resiliency)? All ultimately laid down in a programme of requirements or design brief.
- *Design cycle*: several iteration cycles will be needed (Figure 2), starting with a first exploration of a design issue and assignment to come to a definitive problem definition and design objectives as a hypothesis for further analyses of involved systems and environment, informing the first design concept or alternatives. After evaluation of objectives and validation of specifications further analysis can be needed prior to further elaboration and refinement into an ultimately final design.

APPLICATION
Within all phases of transport and water infrastructure development, to guide the process and strengthen on the degree of integration, supportive to project management. It can be combined with many methods or techniques like research by design, the environmental indicator, multi-criteria analysis, etc.

LIMITATIONS
The lenses are not a substitute for dedicated methods, techniques or tools but an aid to integrated infrastructure design.

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FURTHER READING ■ **Riedijk, M., Sijmons, D.F., Hertogh, M.J.C.M., Rots, J.G., Geerts, F., Schmets, A.J.M., Van der Velde, J.R.T., De Boer, J.J., & Wilbers, J. (2013).** ***Integraal ontwerpen van infrastructuren: Aanzet tot een agenda voor onderwijs en onderzoek.*** **TU Delft, Deltas, Infrastructures & Mobility Initiative (DIMI).**

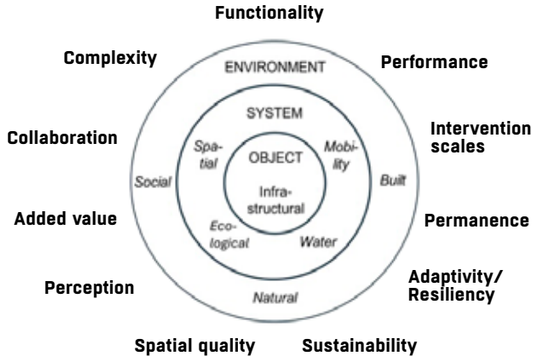


Figure 1. Lenses as focal point for an infrastructural object integrated into its relevant system(s) and environment. Lenses can be combined as coherent sets covering various aspects and levels. [Hans de Boer]

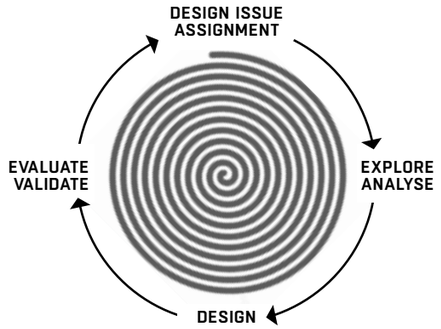


Figure 2. Simplified design cycle in which lenses can be applied in all phases, together with methods, techniques, and strategies. [Hans de Boer]

Functionality	Will an object support its purpose? Useful and necessary? Can we combine functions to serve different purposes? Create more value and/or reduce costs?
Performance	How to secure performance in terms of reliability, availability, maintainability, and safety (RAMS) during its life cycle (design, build, maintenance, and renewal)?
Intervention scales	A single object or part of a local or regional network? Neighbourhood, city, or landscape? Intrusive, dominant? Invisible or iconic landmark?
Permanence	Buildings and structures have a lifespan of many decades or even some centuries between built, renovation and demolition. Routes between cities and city plans can be there for many centuries. Is there a tabula rasa or tabula scripta to deal with? A green field? Can we make use of existing value and quality?
Adaptivity/ Resiliency	How future-proof? What if future use changes significantly? What if future conditions change significantly? Will the design be flexible or robust enough? Maintainable and adaptive to other uses or to different conditions? Restorable?
Sustainability	Can we design, construct, and exploit infrastructure with a smaller ecological footprint? Less use of natural resources? Zero emissions? Use of renewable materials and energy? Improve the (natural) environment and ecology?
Spatial quality	Are spaces, places, and their structures meaningless or do they express an identity? What is their economic, social, ecological, and cultural-historical value? What about user experience? What about present and future use and value?
Perception	What will be the perception of locations and scenery by commuters or travellers with different modes of transport and speeds? And of users or residents?
Added value	How to create social, cultural, economic, and/or environmental benefits? What will be the business and value case that attracts investors, justifies investments, and creates commitment from politicians, citizens, and other stakeholders?
Collaboration	Will engineers, designers, managers and policy advisors understand each other as specialists in their own field in approaching a complex social issue? How to bring this together? What about the involvement of interest groups and citizens?
Complexity	How to deal with the complexity of a design issue, its actual design and realization? Is it technical, political, administrative, legal, organizational and managerial, social, or financial? Or all at once?

Table 1. Overview of lenses and questions which can be useful to support the dialogue between clients, designers, experts and stakeholders in distinct phases.

Morphological Analysis

Designing within the infrastructure domain is often the design of 'usefulness and necessity'. This mainly relates to the functionality and the components that are needed for this. At the same time, citizens expect more and regulations set higher requirements. How to be still innovative?

PURPOSE – A morphological analysis, as applied within the design and engineering disciplines, aims to systematically generate, inventory, and combine form-based solutions for characteristic functions or performances of a product or object, system, service or process. A morphological chart or matrix is used to show promising combinations of often familiar solutions, which can serve as alternative concepts for further analysis and design, based on the concept of relation, which involves exploring new ways of connecting (Beheshti, 1999). It assumes an open attitude and approach of involved designers and engineers in generating solutions (diverging) to increase the solution space and to increase the chance of finding new combinations to inform the design (converging) (Heijne & Van der Meer, 2019).

Morphology as a concept involves the study of form. In the context of design and engineering, Zwicky (1969) pioneered in developing morphological analysis "as a problem-structuring and problem-solving method for exploring possible solutions to a multi-dimensional and non-quantitatively complex problem". In the context of integrated design of infrastructure, it is about the object – as an integration of functions and structural components – for which a morphological analysis can be helpful to expand design possibilities, and where system and spatial integration are important. In transport and logistics, the demand for transport, the supply and choice of transport modalities, the network, and the traffic itself are important elements to consider in the analysis. In water management the boundary conditions related to flood protection and ecology are relevant factors. In urban design and landscape architecture are structure, form, patterns, soil, ownership, and use, among others, factors to consider.

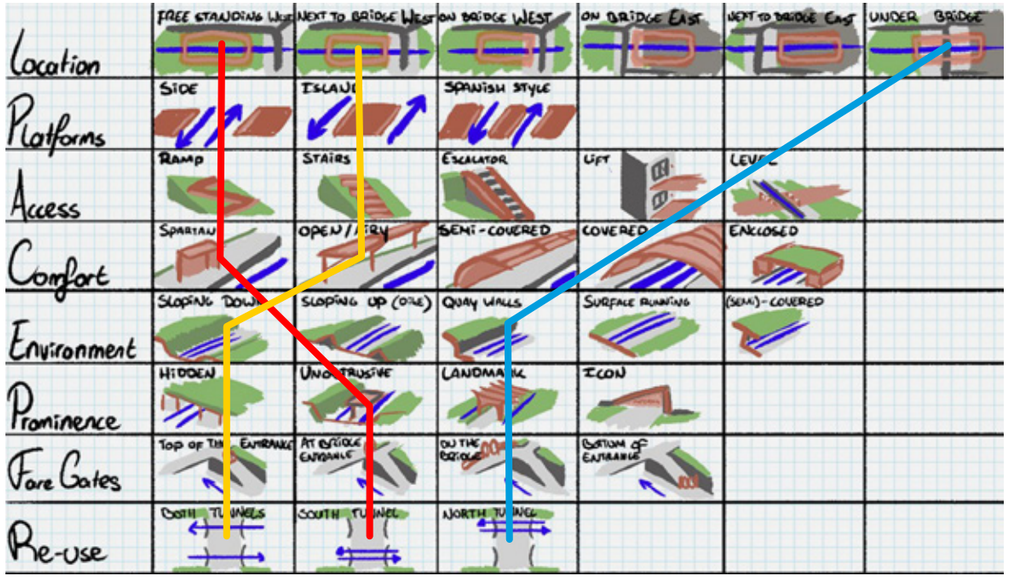
APPROACH – When designing infrastructure, the requirements, specifications, or performance levels are given. A morphological analysis can confront and inform design using the following integrative aspects: (a) determine the characteristic functions and/or aspects of the object to be designed and generate and inventory different solutions for each; (b) determine the interfaces and boundary conditions that are relevant to the system integration of the object and generate and inventory various solutions/measures; (c) determine the spatial relations and boundary conditions that are relevant for the spatial integration of the object and generate and inventory various solutions/measures; (d) make three or four combinations to keep the analysis manageable by connecting different solutions per characteristic function or aspect. Look for less obvious combinations so that they can possibly serve as the basis for an innovative concept (Heijne & Van den Meer, 2019).

APPLICATION
Problem-solving and concept development within many design and engineering fields. Within a supervised multi-, inter- or transdisciplinary setting it can incorporate various insights and solutions from which innovation can arise.

LIMITATIONS
The approach is a form of abductive reasoning which means that chosen combinations could be arbitrary. Make use of a multi-criteria analysis to assess the concepts/alternatives.

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FURTHER READING ■ Baggen, J.H., & Van Ham, J.C. (2019). *Het transportsysteem.* Delft Academic Press / VSSD ■ Beheshti, M.R. (ed.) (1999). *Handboek systematisch ontwerpen in de civiele techniek en bouwkunde. Een naslagwerk ten behoeve van systematisch, methodisch en functioneel ontwerpen.* Delft University Press ■ Heijne, K., & Van der Meer, H. (2019). *Roadmap for creative problem-solving techniques. Organizing and facilitating group sessions.* Boom ■ Zwicky, F. (1969). *Discovery, Invention, Research – Through the morphological approach.* The MacMilian Company ■ Billiard, J.B., Bleijs, J., Blomberg, T., Bouzeya, I., Breukel, J., & Hoogkamer, K. (2025). *Dokpark Metro Station.* Student report Interdisciplinary and Collaborative Design Project (CT3201). TU Delft, Minor Integrated Infrastructure Design.



Metro station design: example of a morphological analysis and chart for the design of a sustainable, circular, nature-inclusive metro station by a multidisciplinary student team. The rows refer to the characteristics of the metro station, its interface with the transport system and its spatial relation to the environment. The platforms, access, comfort, and fare gates refer to its functionality. The location, environment and re-use aspects refer to the horizontal and vertical alignment of the station to the tracks and an existing bridge with a tram line on top over a car tunnel. Prominence refers to architectural design. The columns show the several viable solutions. The three combinations shown by the coloured lines represent different choices for each function or aspect.





The final design proposal – as a mix of the alternatives – shows the choice to locate the station location under the bridge, so no building was needed, only shelters on the platforms. The ramps to the viaduct with the fare gates provide access to the side platforms while bridging the differences in height. At the same time, they are part of a landscape environment in which both the traveller and small urban animals feel at home. The ramps are also part of a dike for flood protection because of a nearby tunnel entrance under a river (Billiard et al., 2025).

Motorway and Railway Line Tracing

Getting from A to B suggests efficiency and effectivity from a mobility perspective. However, before this can become reality, infrastructure, as the physical connection, is needed within the built and natural environment. What conditions will a planner or designer meet for a new connection – tabula rasa or tabula scripta? How to take the environment into account?

PURPOSE – Line tracing is about finding the best route from A to B for transport infrastructure on a large spatial scale. The best route for a new motorway or railway offers a good balance between the best traffic engineering solution with the lowest construction costs and the least adverse effects on the environment.

Mainly after the Second World War, the Netherlands began to plan and build motorways on a large scale. Things went especially fast in the 1960s. At that time, the focus was on connecting as quickly as possible without taking the environmental effects of the new infrastructure into account. Nowadays that is no longer possible.

To arrive at one or more promising alternatives for a route, a thorough exploration of the landscape is needed based on following a step-by-step plan. This as part of the process of plan exploration to ultimately arrive at a formal route decision.

APPROACH – To determine the best route between points A and B, the following steps are required.

1. *Determine the destinations to be connected:* put the destinations that need to be connected on an up-to-date topographic map. The destinations are the start and end points of the new connection, but also intermediate destinations (Figure 1). Check the situation according to the map in the field as well. Are the roads and buildings that have been built recently also on the map?
2. *Delineate the search area:* the search area consists of the area between the starting point and the end point of the new connection. The search area must be so large that all routes to be drawn up are within the area.
3. *Perform a sieve analysis:* establish a limited number of spatial exceptions. The routes that are yet to be drawn up may not be drawn through these areas. Common exceptions are densely built-up areas, nature reserves and cultural-historical objects. Even with a brief list of exceptions, a situation can arise that no route from A to B is possible. In that case, take a critical look at the exceptions. Maybe too many areas have been excluded?
4. *Identify corridors with a potential surface analysis (PSA):* an additional analysis can be done for the open space from the sieve analysis. Depending on the scale or available geodata, lay for example a 1x1 km grid over the search area (Figure 2). Draw up a limited number of spatial criteria that give an indicative value of an area. Apply the rating to every km² of the grid. The higher the score on the spatial criteria, the less appropriate it is to place the new motorway or railway in that square. Then find routes that connect A and B. Choose

APPLICATION
Tracing of motorways, railways, waterways, regional cycle routes, etc. where there is (still) some open and unprotected space in the landscape. In higly urbanised areas, a tunnel for heavy infrastructure seems to be the only feasible solution.

LIMITATIONS
Tracing through or near nature reserves such as Natura 2000 or areas managed by nature preservation organisations is almost impossible. Physically unsuitable areas due to the soil type or extensive water surfaces make construction very expensive. Previous cuts through vulnerable nature areas have been partly absorbed by the construction of wildlife crossings ('ecoducts').

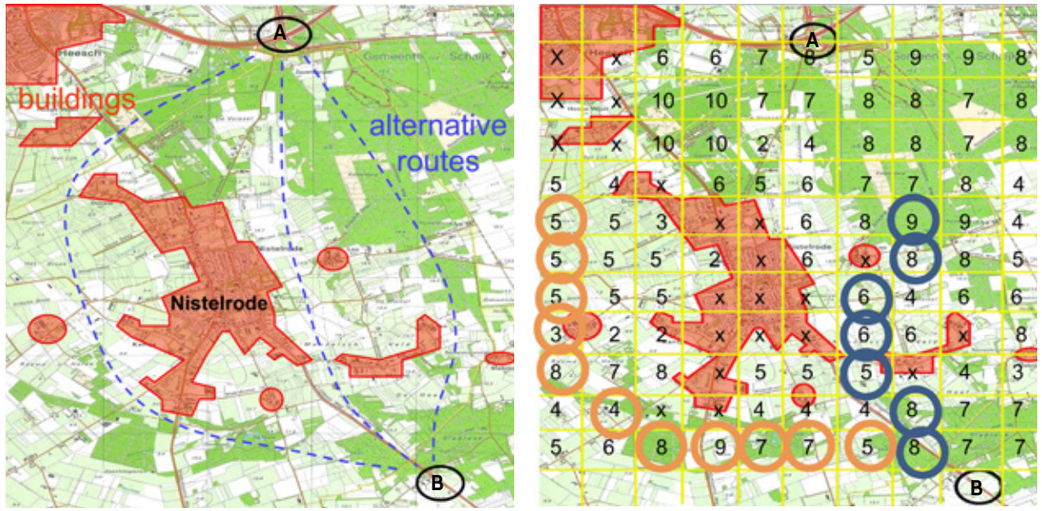
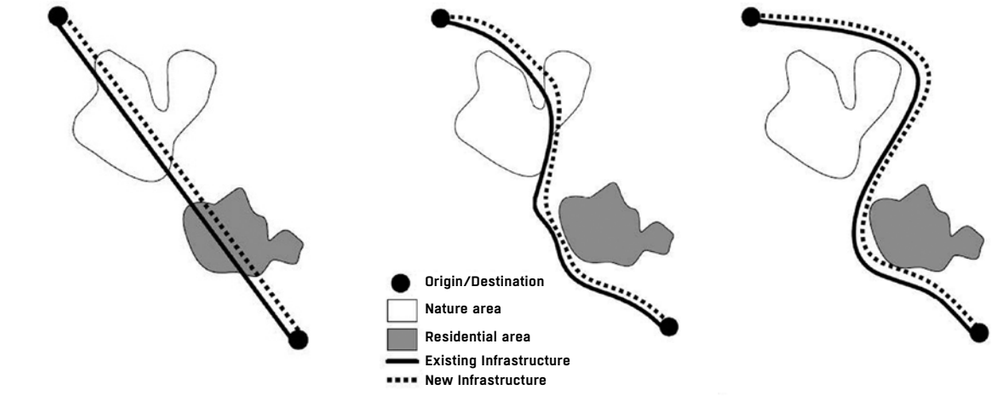


Figure 1 (left): open and unobstructive space is selected based on the marked locations which should be untouched. / Figure 2 (right): a potential surface analysis offers more detail of the open area by a score of its spatial value. A lesser score for an alternative is better than a higher one (Nederveen, 2007). / Figure 3 (below): tracing principles: straight line, bundling with other infrastructure and free tracing (Willems, 2001).



Straight line	This provides the shortest connection, but there is a good chance that the straight line will go right through valuable areas. The straight line can provide good routes in areas with little relief and slight variation in land use, such as large-scale agricultural areas or extensive forests.
Bundling with other infrastructure	In practice, this is often the bundling of a railway line with a motorway. By bundling with existing infrastructure, there is no additional intersection in the landscape and the noise zones coincide. This can strengthen the barrier effect. A tight bundling of a new railway line with an existing motorway is not possible in curves. The minimum radius of a railway line is greater than that of a motorway. Bundling creates residual spaces between the railway and the motorway that are of limited use. This residual space can provide a biotope for flora and fauna.
Free tracing	Free tracing tries to preserve everything of value. The PSA (see step 4) is a way of free tracing. Free tracing can result in a much longer route than the straight line. If the detour is exceedingly long, a tunnel for a section in a straight line may be a better choice.

Table 1. Tracing principles for a route.

routes that run through low-scoring squares as much as possible. The result is one or more routes from A to B.

5. *Determine the horizontal alignment:* there are *three tracing principles* for finding routes (Figure 3 and Table 1). The choice will be based largely on the results from the environmental analysis, which shows the spatial boundary conditions and the impact the route will have on its surroundings. These principles are best suited to flat areas. In the case of hilly or mountainous areas, other considerations are needed.

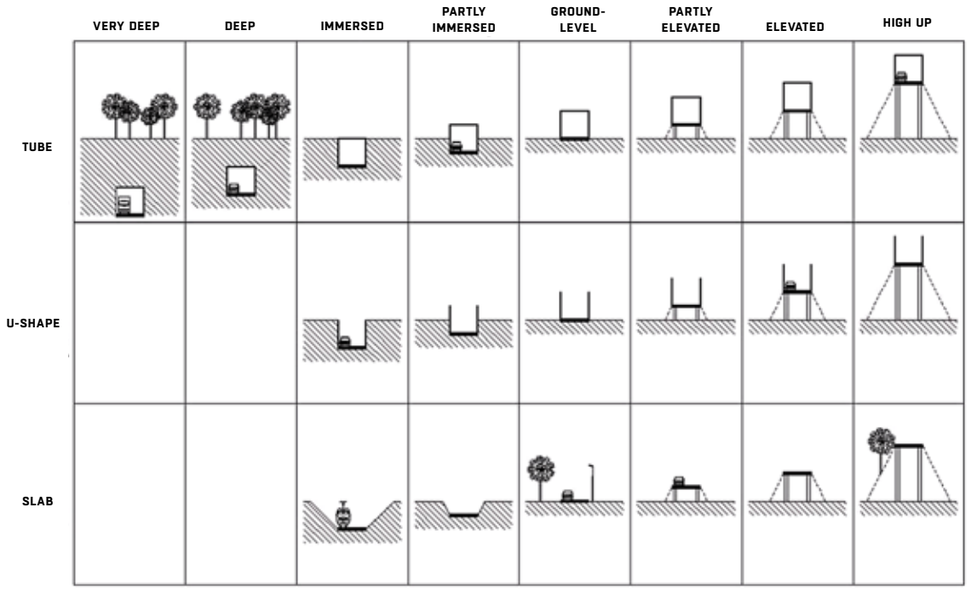
6. *Determine the vertical alignment:* the ground level or a slightly elevated location is the cheapest and most popular solution (Table 2). In the case of intersections with other infrastructure, the costs often determine which infrastructure will be placed at ground level and which goes above or below it. A tunnel is an option in areas where there is no more space above ground for the new connection. The immersed open box is another possible solution – as used for the A4 Midden-Delfland motorway and the A24 Blankenburgverbinding – to reduce noise and visual disruption when cut through a natural area. Different sections of a route can have a different elevation which should properly aligned with each other considering the design parameters: height difference; percentage, length, sag and crest curve of the connecting slope; and the maximum traffic speed.

Jan Nederveen, Municipality of Delft

FURTHER READING ■ Baggen, J.H., & Van Ham, J.C. (2019). *Het transportsysteem.* Delft Academic Press / VSSD ■ Nederveen, A.A.J. (2007). *Ruimtelijke inpassing van lijninfrastructuur. Een onderzoek naar de geschiktheid van inspraak-reacties voor het beoordelen van lijninfrastructuurontwerpen.* Doctoral thesis. TU Delft ■ Wikibooks-contributors. (2025, 26 August). *Infrastructuurplanning.* Wikibooks. https://nl.wikibooks.org/wiki/Infrastructuurplanning ■ Willems, J.C.A.S. (2001). *Bundeling van infrastructuur. Theoretische en praktische waarde van een ruimtelijk inrichtingsconcept.* Doctoral thesis. TU Delft.



A1, Naarden, North Holland: re-routing and widening of the motorway, initially with a bridge over the Vecht River, with the road now passing under an aqueduct. [© Rijkswaterstaat] **/ Table 2 (below): elevation options for infrastructure.** [© Jan Nederveen, Lindy Molenkamp, Enne de Boer]



Multi-Criteria Analysis

Functionality, integration, effects, and costs play an important role in infrastructure planning and design. How to present and assess alternative solutions in a clear way? Does the best solution emerge from such an analysis?

PURPOSE – The aim of a multi-criteria analysis (MCA) is to gain insight into the best solution for an infrastructure task. In the case of multiple possible solutions, the question arises as to which solution is the best choice. The client wants to know what the pros, cons and effects are for each of the alternatives to be investigated. There are several methods for comparing alternatives, like a (social) cost-benefit analysis; the difference between the methods is in the way in which the total score of the alternatives is determined. Drawing up a scorecard is the same for all methods and provides a summary overview of the advantages and disadvantages. The simplest method does not calculate a total score, while the more complicated methods convert all or part of the effects to money, or a dimensionless number with or without some weight.

An MCA and its scorecard are not by definition value-free. Alternatives and aspects can be connected to different stakeholders. Compiling aspects and presenting scores requires care to prevent likes or dislikes from being resonated, apples and oranges being compared, or costs being all-important without paying attention to value. The latter can be overcome by a cost-benefit ratio per alternative. There is no 'best' choice when scores are close to each other. In case of design, it must be verified whether all alternatives meet basic requirements and boundary conditions. An MCA is especially useful to focuses and validate purpose and wishes.

APPROACH –The approach below is limited to drawing up a scorecard.

1. *Draw up alternatives*: a good scorecard includes the following alternatives: (a) *The current situation*, as the basis to which other alternatives are compared. Without a 'null alternative', no improvements can be observed. (b) *The current situation, say in 15 years*, with only established policies to see if the problem gets worse over time. (c) *The 'null-plus alternative'*, proposing simple and cheaper measures that will also solve or reduce the problem instead of building new infrastructure. (d) *New alternatives*, consisting of a few solutions.
2. *Determine relevant aspects*: this is necessary in order to be able to compare. Information should be collected based on: (a) old scorecards, (b) arguments used in the political discussion about the proposed plan, (c) the goals of the project, (d) the expected effects and side effects, (e) interviews with stakeholders.
3. *Organize aspects into main groups*: related aspects are merged under one main group, and duplicates are removed. This works best for line infrastructure projects such as motorways and railways.
4. *Define aspects*: for each aspect, describe the method by which the effect can be determined where possible so that it is verifiable and reproducible. It is not necessary to force all aspects to be expressed in + or –, an ordinal number, or in money. Stay as close as possible to the indicator from which an aspect can best be defined.

APPLICATION
Various civil engineering infrastructures such as roads, railways, bridges, tunnels, dikes, locks, seaports, airports, etc.

LIMITATIONS
Be aware that:

- Main groups could be represented as more important than necessary because of various aspects.

- Different colours are applied correctly in case of small differences in aspects.

- If an alternative is the only one that scores very well or very badly on an aspect, take a closer look if this really is the case.

Aspects	Null	Null 15 years	Null plus	Alternative A	Alternative B	Alternative C
Main group 1						
Aspect a						
Aspect b						
Aspect c						
Aspect d						
Main group 2						
Aspect e						
Aspect f						
Main group 3						
Aspect g						
Aspect h						
Main group 4						
Aspect i						
Aspect j						
Aspect k						

Example of a scorecard design that includes all 'null' alternatives.

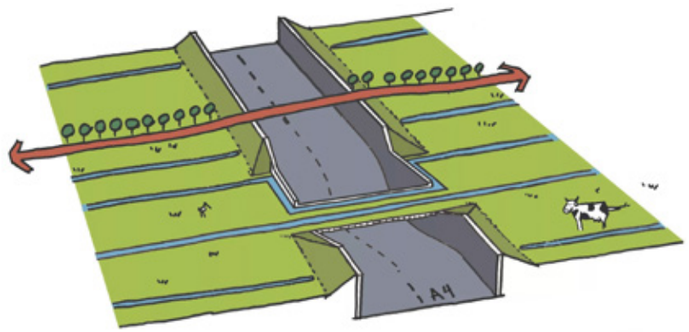
Alternative/Variant	Null	A4		A13 + A24		A13	MEA	Tram
		Ground	Sunken	Ground	Sunken	A16		
Main groups				2 x 5 lanes	2 x 5 lanes			
Traffic and transport	- -	-	-	0	0	-	-	- -
Spatial planning	0	0	0	- -	- -	- -	0	0
Economy	0	+ +	+ +	+	+	+	+ +	0
Landscape	0	-	-	- -	- -	-	0	-
Noise	0	- -	-	-	-	0	-	-
Air	0	+	+	0	0	-	+	0
Road safety	0	+	0	-	-	0	+	0
Social aspects	0	-	-	-	-	-	0	-
Recreation	0	-	-	- -	- -	-	0	-
Costs – low (M€)	15	370	780	1,340	1,470	1,685	1,710	120
Costs – high (M€)			1,300		1,890			

Scorecard motorway A4, Midden-Delfland, South Holland: simplified scorecard for the decision-making in 1996 about the new A4 Delft-Schiedam motorway, partly running through a valuable polder landscape. Alternative solutions were the widening of the A13 (2 x 5 lanes) and/or the construction of an extension of the A16 to the A13, or the construction of a new A24 motorway (2 x 5 lanes). In the political discussion, solving traffic jams was contrasted with the preservation of the polder landscape. In this scorecard, the scores are displayed on a +/- scale and compared to the null alternative. The most eco-friendly alternative (MEA) has the best scores but is also one of the most expensive alternatives. The combination of the widening of the A13 with the construction of the A24 is the best in terms of traffic, but scores poorly on all other aspects. The A4 at ground level seems to be the best choice but scores the worst on noise pollution. To accommodate the opponents of the road, a sunken location of the A4 was eventually chosen (Nederveen, 2007).

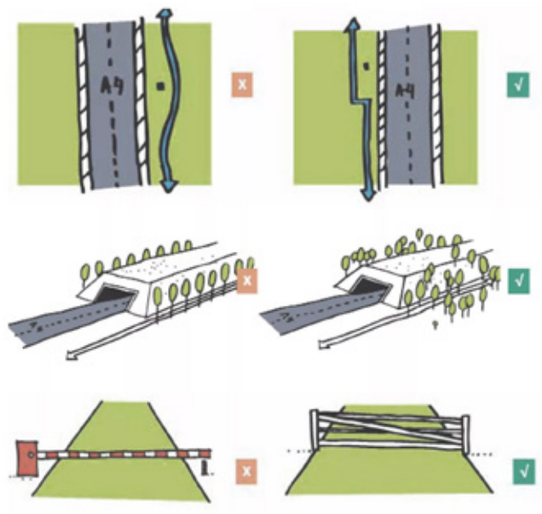
5. *Set up the scorecard*: the columns show the alternatives. The main groups and the aspects form the rows. A clear scorecard compares at most eight alternatives.
6. *Compare the alternatives*: colour scores on aspects red (worst), yellow and green (best). Give scores that are close to each other the same colour. Determine the colour of the main group based on the colours of each aspect. This provides enough information to separate the better from the less favourable alternatives. Additionally, a sensitivity analysis could be executed in case data is used.

Jan Nederveen, Municipality of Delft

FURTHER READING ■ Baggen, J.H., & Van Ham, J.C. (2019). *Het transportsysteem.* Delft Academic Press / VSSD ■ Nederveen, A.A.J. (2007). *Ruimtelijke inpassing van lijninfrastructuur. Een onderzoek naar de geschiktheid van inspraakreacties voor het beoordelen van lijninfrastructuurontwerpen.* Doctoral thesis. TU Delft.



A4 Delft-Schiedam: design principles for the landscape integration of the motorway through Midden-Delfland. [© BoschSlabbers landschapsarchitecten]









A4 Delft-Schiedam, South Holland: sunken motorway through the Midden-Delfland polder area, minimizing noise and visual disruption and maintaining waterways, with the Kethel land tunnel at Schiedam. [© Jeroen Musch (top) / © Rijkswaterstaat, Joop van Houdt (middle)] / **Below: lowered lightning to reduce spill-over in the landscape.** [© Heijmans, Marc Blommaert]



Rainbow Model

Infrastructure projects are complex due to their scale, impact, uncertainty, ambiguity, the multitude of stakeholders, and the continuously changing playing field. How to gain insight into the various perspectives involved and how to embrace these?

PURPOSE – The purpose of the rainbow model is to recognize and incorporate multiple perspectives in complex projects. These perspectives should be both individually designed and organised, and balanced in relation to one another. The model was developed during the planning phase for engagement of stakeholders of the Betuweroute freight railway in the mid-1990s (Hertogh et al., 2008). At the time, the client and project delivery organisation were primarily focused on construction and the added value of freight transport, aligned with post-war reconstruction values. There was insufficient focus on other perspectives, especially those of local residents who feared significant nuisance and strongly opposed the project. Eventually, a broader focus emerged. Residents were taken seriously, leading to a shift toward a more open and inclusive approach. Notably, archaeological discoveries made during construction were no longer seen as obstacles to progress, but as societal assets. A dedicated organizational unit called 'the antenna' was created to monitor current and potential future changes in the surrounding environment and society. The model has been applied in various projects and presented at international conferences.

APPROACH – The model distinguishes five key perspectives, and their main focus, each prefixed with 'inter' to emphasize their integrative nature (Figure 1). Different individuals may prioritize different perspectives.

1. *Construction:* inter-disciplinary, requiring collaboration across multiple disciplines. For example, the technician installing safety systems in the tunnel may focus on this perspective.
2. *Stakeholders:* inter-actor, including residents and organisations, numerous in such projects. A local resident concerned about nuisance resulting from the construction may emphasize this perspective.
3. *Transport:* inter-modal; the transport network encompasses relevant infrastructures such as roads, waterways, railways, airports, public transit, cycling routes, and pedestrian paths. A commuter may relate to this perspective.
4. *Combining functions:* inter-functional, such as urban development next to infrastructure, green energy and ecological zones that promote health and biodiversity. An urban planner may prioritize this perspective.
5. *Societal impact:* inter-value, ensuring that perspectives generate value for society in all its dimensions, including nature. A resident living in the city may value this perspective.

APPLICATION
The model can be used throughout all project phases, but it is especially valuable during initiation, planning, and preliminary design stages. Additional perspectives can be added like finance or legislation to tailor a project.

LIMITATIONS
The model does not prescribe how to approach each perspective and to achieve balance among them. This is a concern for project management (Hertogh et al., 2008). The primary aim of the rainbow model is to foster awareness of multiple perspectives throughout the project life cycle.

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FURTHER READING ■ Hertogh, M.J.C.M., S.K. Baker, P.L. Staal, & Westerveld, E. (2008). *Management of Large Infrastructure Projects,* NETLIPSE ■ Hertogh, M., & Hooimeijer, F. (2025). *Building Futures, Integrated design strategies for infrastructures and urban environments.* TU Delft Deltas, Infrastructures and Mobility Initiative (DIMI) ■ Hertogh, M., & Houwing, E. (2025). *Dictaat CTB1220, Integraal Ontwerp en Beheer.* TU Delft.

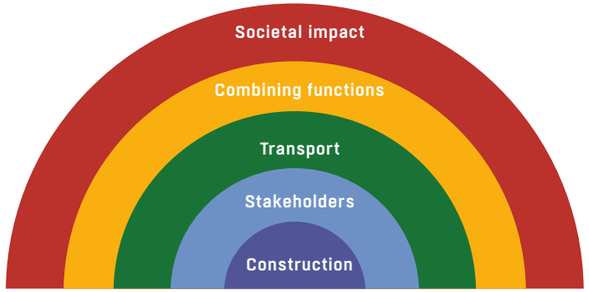




Figure 1. The five perspectives of the Rainbow Model. (Marcel Hertogh) **/ The stacked tunnel mouths in De Groene Loper, Maastricht, a comprehensive plan for traffic infrastructure and urban development.** [© Ballast Nedam, Fred Berghmans]

Perspective	Focus	Key concept	Examples from De Groene Loper
Construction	inter-disciplinary	collaborating between technical disciplines	tunnel design, safety systems, structural engineering, realisation
Stakeholders	inter-actor	aligning residents and interest groups	involvement of the community in planning and during realisation
Transport	inter-modal	connecting multiple transport modes	modalities integrated into local, regional and national network
Functions	inter-functional	adding new functions	housing, offices, green spaces, leisure areas, image of the city
Societal impact	inter-value	creating value for society as a whole	optimizing sustainable and resilient development: healing the city, improving mobility and liveability, enhancing nature

The name Groene Loper (The Green Ribbon) refers to the long tree-lined boulevard that runs over the tunnel through Maastricht-East. The construction consists of a double-decker traffic tunnel: the lower deck accommodates through traffic, while the upper deck connects to the local road network. By placing the motorway underground, the barrier between neighbourhoods on either side of the former ground-level highway was removed. The city was effectively 'reunited'. Above the tunnel, space was created for new landscaping, such as housing and office development. / Below: aerial view of De Groene Loper. [© Ballast Nedam, Bert Janssen]



Reliability Assessment

Infrastructure is designed and constructed to endure for decades and to withstand the elements. But can we deal with what we foresee and what we do not foresee? Can it fail?

PURPOSE – The purpose of a reliability assessment is to determine, quantify, and improve the ability of a system or structure to perform its intended function for a specified period of time under defined operating conditions (Reeve, 2010). The outcome of a reliability assessment is a judgement about the likelihood of functioning of a structure or system, given uncertain circumstances and characteristics. Reliability in this case is the *probability of non-failure*, which is complementary to failure probability, that is, the likelihood of occurrence of an event that leads to dysfunction of the structure or system (for example, the collapse of a bridge or the derailment of a train). The reliability of a system or structure is in general expressed in terms of *solicitation S* (for example loading) and *resistance R* (for example stability and strength). If there would be no uncertainties, a system or structure would be considered reliable if $S < R$. We speak of failure if $S > R$, in which case the system or structure cannot fulfil its required function.

APPROACH – When developing a design, uncertainties must be included in a reliability assessment. They can be classified by four main categories (Table 1). To account for these uncertainties, an engineer or technical designer must build in a *safety margin* between the expected (extreme) loading and the strength or resistance of the system or structure. For a structural design there are various *calculation techniques* available to incorporate a safety margin, which are classified according to the following four levels.

- *Level 0: deterministic design,* based on experience or engineering judgement, overall safety factors are applied to create a margin between the expected values of loading and strength.
- *Level I: semi-probabilistic design,* where load and strength are treated as *stochastic variables*, which means that their potential values are distributed around a mean value μ (Figure 1).
- *Level II: simplified probabilistic design,* to overcome the drawbacks of a full deterministic design.
- *Level III: full probabilistic design,* which are approaches in which the potential value distributions of all stochastic variables are described and included in the analysis (Figure 2). Level III methods can become extremely complex in case of multiple failure modes or structural parts.

APPLICATION
The techniques can be applied to a wide range of systems or structures; for example, flood protection systems, nuclear power plants, aircraft and aviation systems, bridges and structural engineering, water supply and treatment systems, railway signalling and control systems, medical equipment, telecommunication networks and energy distribution systems.

LIMITATIONS
Implementing reliability assessments often requires significant investment in resources, including specialised software, specialists, and detailed testing. It usually involves complex mathematical models and assumptions. This can make the analysis time-consuming and difficult to implement. Furthermore, these typically rely on predefined failure modes and statistical data (e.g., failure rates of components), but these assumptions may not always represent real-world conditions. Unforeseen or rare failure modes may lead to an underestimation of risks. There is an overemphasis on quantification, which is especially difficult for human factors.

Mark Voorendt, TU Delft

FURTHER READING ■ Kiureghian, A.D. (2022). *Structural and system reliability.* Cambridge University Press ■ Melchers, R.E. (2002). *Structural reliability analysis and prediction.* John Wiley & Sons ■ Onderzoeksraad voor Veiligheid. (2018). *Bouwen aan constructieve veiligheid. Lessen uit instorting parkeergebouw Eindhoven Airport.* Onderzoeksraad voor Veiligheid ■ Reeve, D. (2010). *Risk and reliability: coastal and hydraulic engineering.* Spon Press.

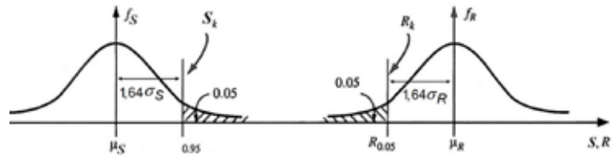


Figure 1. Solicitation (*S*) and resistance (*R*) as stochastic variables. The characteristic value of the load S_k is the value that is exceeded by only 5% of the samples (at left). The characteristic value of the strength R_k usually is the value that is exceeded by 95% (at right). S_k and R_k are converted to design values S_d and R_d with help of partial safety factors. In the end, a structure or system is considered safe if $S_d < R_d$.

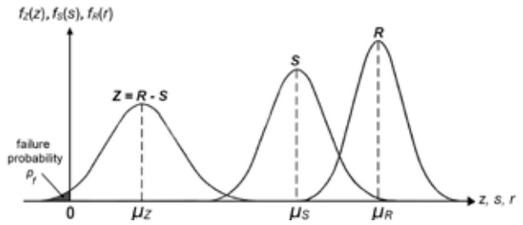


Figure 2. Distribution of potential values of loading $f_S(s)$ and strength $f_R(r)$, plus the distribution of the limit state function $f_Z(z) = f_R(r) – f_S(s)$. A 'wide' distribution around the average limit state value μ_Z implies a large uncertainty, while a 'tight' distribution indicates a high certainty. The failure probability P_f is represented by the area $Z < 0$ (the small black area left of the vertical axis). If the failure probability is lower than the acceptable target failure probability, the structure or system is considered sufficiently reliable.

Physical or inherent uncertainties	Randomness or variations in nature. Variables can differ in time (water level, for example), or in space (dike height). These uncertainties are mainly caused by a lack of data of loading or strength.
Statistical uncertainties	The distribution function of the possible values for loading or strength is not exactly known, or the parameters of the distribution function are determined with a limited amount of data.
Modelling uncertainties	Imperfectness of models or failure modes, describing natural phenomena. This can be caused by a lack of knowledge of these phenomena or by over-simplification. Financial uncertainties (like construction costs and damage costs) are comprised in this category.
Human error	Often forms a big threat to the reliability of a structure.

Table 1. Main categories of uncertainties to consider when developing an engineering design. / Below: Eindhoven Airport: collapse of floors in a car parking under construction in 2017. Investigation showed that the direct cause was the design decision to place floor plates in an unusual way. Indications during the construction that something was wrong were incorrectly interpreted and neglected due to a lack of clear responsibility concerning safety risk management amongst the partners of the construction consortium (Onderzoeksraad voor Veiligheid, 2018). [© ANP, Rob Engelaar]



Risk Assessment

Infrastructure is a vital part of society, but 100% operational availability would be extremely complicated and expensive. Potential risks that reduce the operational availability are identified and evaluated using a risk assessment.

PURPOSE – The purpose of a *risk assessment* is the quantification of the severeness of an event in terms of probability of occurrence and its consequences. *Risk* (*R*) is in engineering usually defined as the product of the probability of failure (p_f) and the consequences of failure (*C*): $R = p_f \cdot C$.

- *Probability* is the likelihood of occurrence of an event (for example, the collapse of a parking garage, a helicopter crash, or a flood), quantified in a range from 0 to 1 (or 0 to 100%). The *consequences* of the event can be quantified in terms of economic damage or the loss of life. Consequences are the product of the total potential losses and the actual exposure to the event.
- *Risk* in this sense is complementary to *safety*, which is "a state in which the risk of harm to people or material damage is limited to an acceptable level" (ISO-code 8402).

APPROACH – The risk level that is considered acceptable is subjective and depends, amongst others, on the extent of voluntariness of exposure to the threat, the recognisability of the threat, and the social advantages of opposing the risk. Four criteria can be used to determine what risk level is considered acceptable: 1. *Individual casualty*: the probability that an individual, continuously residing at a certain place during a year, dies due to an undesired even. 2. *Multiple casualties*: the probability that a (large) number of individuals dies due to an undesired event. This is considered a measure for societal disruption. 3. *Economic*: the investments in reducing the failure probability should balance the reduced economic risk (Figure 1). 4. *Spatial quality*: ecology and culture, which are difficult to include in a quantitative risk assessment.

Risk assessments are used as part of practical and structured approaches to deal with risks in infrastructural projects. One of those methods is RISMAN, often combined with a strategic analysis model to assess macro-environmental factors, also known as PESTEL (politics, economic, social, technological, ecological, legal). The method uses the following four steps:

1. Determining the objective.
2. Mapping the risks in, for example, a risk diagram (Figure 2).
3. Quantifying the most important risks (the actual risk assessment).
4. Mapping control measures.

The RISMAN method involves a continuous risk identification and discussion, ensuring that all stakeholders participate in the process. This initiative-taking approach involves identifying and implementing control measures before risks materialize, which is an iterative process requiring open communication.

APPLICATION

Risk assessments are widely applied across various domains, including healthcare, environmental management, finance, engineering, and cybersecurity.

LIMITATIONS

Risk assessments rely on incomplete or uncertain data, which can lead to inaccurate predictions. In addition, they may not account for all potential risks, especially rare or emerging threats. Risk assessments are typically based on past experiences or historical data, which might not always reflect future conditions.

Mark Voorendt, TU Delft

FURTHER READING ■ Aven, T. (2016) Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 25*(3), 1-13 ■ Moss, R.E.S. (2020). *Applied civil engineering risk analysis.* Springer ■ Bedford, T., & Cooke, R. (2001). *Probabilistic risk analysis. foundations and methods.* Cambridge University Pres.

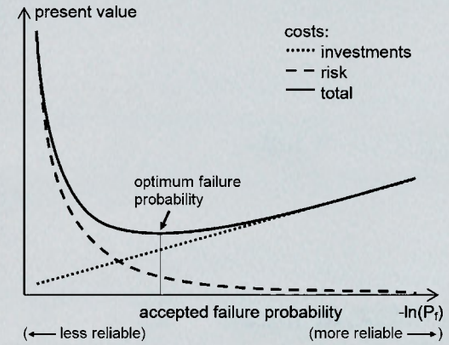


Figure 1. The optimum failure probability of a system or structure in an economic sense can be found by balancing the investments to avoid failure and the reduction of the risk due to the investments.

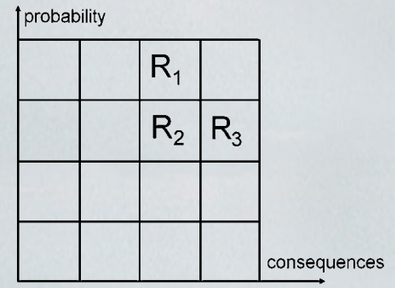


Figure 2. Risk diagram with a few classified risks as an example (R1, R2 and R3). Risks with a low probability and low consequences are acceptable. Risks with a high probability and high consequences have to be avoided.



For buildings outside a dike, a higher level of flood risk must be accepted than for the area inside, which is protected by the dike. [© Rijkswaterstaat, Room for the River]

Social Cost-Benefit Analysis

Does a decision maker know all the advantages and disadvantages when deciding for a large infrastructure project? How to deal with uncertainty and the lack of insight in the positive and negative social effects of an infrastructure? An assessment method like a social cost-benefit analysis (SCBA) can help to answer these questions.

PURPOSE – The idea of an SCBA is that decision makers gain insight into the social effects of a policy measure, in this case new or improved transport infrastructure. The analyst attempts to quantify all advantages and disadvantages as much as possible and express these in monetary terms (e.g., euros). This allows the SCBA to determine the balance of benefits minus the costs in euros of a project. If this balance is positive, the infrastructure project contributes positively to welfare; if the balance is negative, the project is welfare-reducing. In the latter case, 'society' must, as it were, put more into the project ('the social costs') than it receives in return ('the social benefits').

The 'S' in an SCBA implies that the balance must also include the costs and benefits of effects without market prices. For many social effects without market prices there are techniques available to still estimate a price, such as the concept of 'value of time' (VoT) which denotes the price people are willing to pay to save one hour of travel time. This is also possible for effects such as travel time reliability, comfort (in rail projects), nature, landscape, emissions, safety, cultural history and so on. By expressing all social effects in monetary terms, they become mutually comparable, and the analyst can estimate the final balance. However, it is sometimes not possible to give a price tag to a specific social effect. In that case the analyst must express this in qualitative terms.

APPLICATION
An SCBA is mandatory in the Netherlands since 2000 for large infrastructure. Policymakers do not use the SCBA as a yardstick when choosing whether to implement an infrastructure project, because SCBA is a relatively complicated and controversial instrument. However, research shows that they use SCBA to get a feel for the infrastructure project's desirability from a societal perspective and to determine the major costs and benefits.

APPROACH – Romijn and Renes (2013) provide a roadmap on how to implement the SCBA (Table 1). An SCBA begins with a problem analysis to arrive at a project that matches a real problem or opportunity for improvement. Establishing a baseline alternative is important because the new infrastructure project is measured against baseline development. The social impacts of the new infrastructure, for example travel times, are the difference between the travel time development in the project alternative and in the baseline. After estimating all costs and impacts and identifying the uncertainties and economic risks, the analyst presents the results in a overview table like Table 2.

The SCBA is not an easy tool, because the requirement is that all social costs and impacts of a project must be estimated. This means that this policy support tool is very model- and data-intensive, especially for large infrastructure projects. In addition, the analyst will have to estimate or take additional data from other sources, such as the price tags used for impacts for which there are no market prices, and transparently explain all the assumptions and report clearly on uncertainties.

LIMITATIONS
A good overview of the criticism of SCBA can be found in Koopmans and Mouter (2020). SCBA is an instrument with intrinsic snags, such as whether it is realistic and moral to express the value of a traffic fatality in monetary terms.

Jan Anne Annema, TU Delft

FURTHER READING ■ Koopmans, C., & Mouter, N. (2020). Chapter One – *Cost-benefit analysis, advances in transport policy and planning, 6*(2), 1-42 ■ Rijkswaterstaat. (2024). *Werkwijzer MKBA bij MIRT.* Rijkswaterstaat, Steunpunt Economische Experstise ■ Romijn, G., & Renes, G. (2013). *General guidance for cost-benefit analysis.* CPB (Netherlands Bureau for Economic Policy Analysis), PBL (Netherlands Environmental Assessment Agency).

1. Problem analysis	• What is the problem or oprtunity and how is it expected to develop? • What is the policy objective in response to this? • What are the most promising options?
2. Establish the baseline alternative	• Most likely scenario in the absence of a policy • Effect = policy alternative – baseline alternative
3. Define policy alternatives	• Describe the measures to be taken • Unpick packages of measures to identify individual elements • Define several alternatives and variants
4. Determine effects and benifits	• Identify effects • Quantify effects • Value (monetise) effects
5. Determine costs	• Resource consumed to implement the solution • Cost may be one-off or reoccurring, fixed or variable • Include only costs additional to baseline alternative
6. Analyse variants and risks	• Identify the main uncertainties and risks • Analyse the consequences for the outcomes
7. Overview of costs and benifits	• Calculate all costs and benefits discounted to the same base year and calculate balance • Present all effects, inclusing non-quantified and/or non-monetized effects
8. Presentation of results	• Relevant, understandable and clear • Explain: transparency and reproducibility • Interpret: what can the descision maker learn from the CBA?

Table 1. Roadmap on how to implement a social cost-benefit analysis (Romijn & Renes, 2013).

Alternative	**Bus rapid transport**		**Tram Industrial zone**		**Tram suburb**	
Variant bridge	***New***	***Existing***	***New***	***Existing***	***New***	***Existing***
Effect 1: Investments	75-100	...	200-250	...	250-315	...
Effect 2: Travel time public transport	27-40	...	35-50	...	33-50	...
Effect 3: Reliability	7-13	...	8-14	...	8-14	...
Effect 4	...	...	...	...	...	...
Etc.						
Qualitative Effect 1	0	...	-	...	--	...
Qualitative Effect 2	-	...	--	...	-	...
Etc.						
Balance monetised effects	-15 a +25	-25 a -35	-30 a -95	-18 a -38	-60 a -125	-48 a -60
Balance qualitative effects	0	0	-	-	--	--

Table 2. Fictitious example which shows a combination of monetised and qualitative effects related to transport alternatives and variants for a bridge. It also addresses the case in which all effects could be monetised due the lack of a price tag. The range of sums of money expresses uncertainties related to different economic scenarios. Sums are in net present value in million euros of the same base year (2024) (Rijkswaterstaat, 2024).

X-Minute City Concept

Infrastructure is never neutral – it shapes how we live. Designing urban infrastructure means designing the city from with a responsible attitude. Can we stimulate active mobility modes and strengthen community life in the neighbourhoods of our car-dominated cities? Which strategies does the X-minute city concept suggest?

PURPOSE – Concepts – like 'complete community' and 'integrated community' (Calthorpe et al., 1991), and the concepts of the 30-, 20-, 15-, 10-, and 5-minute cities – claim to redesign cities of the future by the reduction of passenger transport and the improvement of living and working conditions in local communities. The concepts aim to reduce reliance on cars, promote sustainability, and enhance the quality of life by creating compact, well-connected, and locally-oriented neighbourhoods.

Currently, passenger vehicles – particularly cars – account for a sizeable part of transport-related emissions, worsening environmental pollution and creating public health risks in metropolitan and suburban areas. Eliminating and shortening commuting distances drastically contributes to decreased travel time and noise and environmental and mobility injustice. Reducing traffic congestion in residential communities strengthens quality of life as well as social engagements in the public space. The related emissions decline further, which improves public health and environmental sustainability. As such, applying the 'x-minute city' concept contributes effectively to the creation of sustainable, climate-neutral cities for diverse urban populations – through rethinking urban mobility, while keeping cities connected and open for all people. Yet, while current actions contribute to the x-minute city by focusing on inner cities – usually already compact and with a lot of amenities and facilities – the approach needs to consider different urban condition and demographics across the whole metropolitan area, including periphery and suburban areas. Through a diversified approach to address challenges across different urban areas and demographics, this concept can contribute to sustainable, liveable, and inclusive cities.

APPROACH – Underlying this concept, literature names *six key assumptions* which are supportive to change: (a) The energy transition to renewable-energy vehicles promotes climate-neutral mobility. (b) Rising energy costs will influence urban mobility choices. (c) Active mobility modes promote health. (d) Digital transitions will reduce travel frequency and emissions. (e) Shared economies will shift mobility patterns. (f) Community-based regeneration fosters local ownership of facilities and domestic public spaces.

Yet, while technological advancements like electric vehicles (EVs) offer partial solutions, they do not tackle the underlying issue:

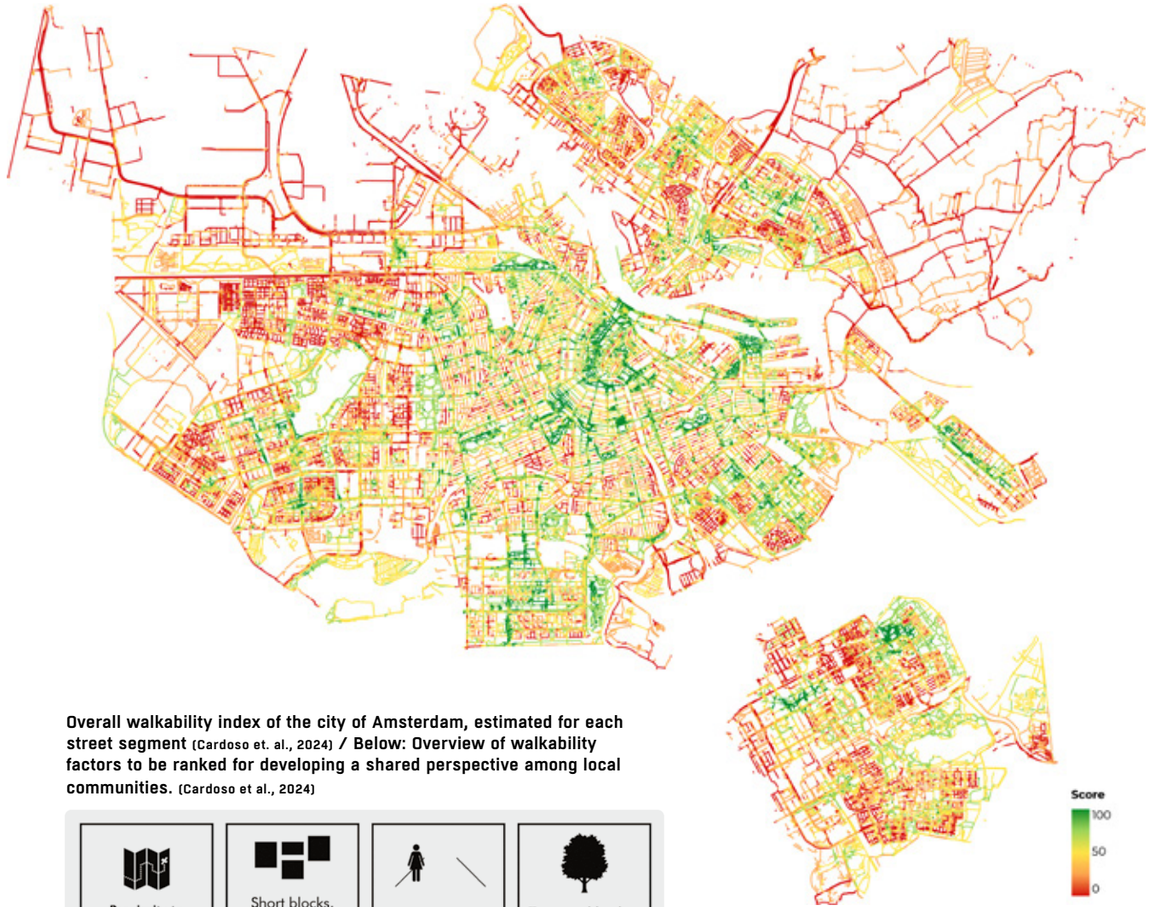
APPLICATION
The concept addresses the increasing strain on urban accessibility and connectivity caused by rapid, irreversible urban expansion, which under current planning and design strategies results in long-distance commuting, traffic congestion, and rising greenhouse gas emissions. It is expected that governance, planning, and design towards the concept, addresses these issues effectively by prioritising the alignment of infrastructure with diverse population needs and by improving neighbourhood live-work conditions.

LIMITATIONS
Applying this concept faces three threats:

1. Persistent top-down approaches may continue to lead to a mismatch between urban structures, public spaces, facilities and amenities and people's lifestyles, perpetuating high-emission mobility.

2. Knowledge needed to diversify urban transformation strategies is fragmented across cities, professions, and academia. It needs to come together.

3. Additionally, integrated, multi-scalar strategies and designs are currently hardly diversified. This hinders effective carbon-neutral transitions in peripheral and suburban areas.



Overall walkability index of the city of Amsterdam, estimated for each street segment (Cardoso et. al., 2024) **/ Below: Overview of walkability factors to be ranked for developing a shared perspective among local communities.** (Cardoso et al., 2024)



human behaviour. The overuse of private vehicles, especially in peripheral areas, drives long-distance commuting and the mismatch between urban structures and lifestyles. The introduction of *proximity* and *density* reduces reliance on transport modes. However, different population groups have distinct needs across the city, which requires careful contextualization of the urban mix. In this context, light commercial vehicles (LCVs) – used for essential logistics and trade services like deliveries and tradespeople – must also be integrated into the application of x-minute cities.

The path to inform planning and policymaking for more sustainable, liveable, and inclusive cities based on incentives for behavioural change involves the following actions:

1. *Measure* the main sources of transport emission, including the impact of fuel and Li-ion battery vehicles and long-distance commuting among diverse populations and in different locations.
2. *Analyse* and localize origins and destinations and the differentiation in travel behaviour, needs, desires, and purposes.
3. *Map* walkability and bikeability with respect to the availability and accessibility of local amenities and facilities, as well as of sustainable interlocal transport systems.
4. *Examine* the diversification possibilities, strategies and incentives in integrated urban design for the x-minute city, as well as in urban governance, planning, and policymaking in order to embed the concept.

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FURTHER READING ■ Calthorpe, P., Corbett, M., Duany, A., Moule, E., Plater-Zyberk, E., & Polyzoides, S., with Katz, P., Corbett, J., & Weissman, S. (eds). (1991). *The Ahwahnee Principles.* Sacramento Local Government Commission ■ Cardoso, M., Milias, V., & Harteveld, M. (2024). Developing a city-specific walkability index through a participatory approach. *Proceedings of the 27th AGILE Conference on Geographic Information Science: Geographic Information Science for a Sustainable Future, Glasgow. AGILE GIScience Ser.*, 5, 2 ■ Moreno, C. (2020). *Droit de Cité: De la «Ville-Monde» à la Ville du Quart d'Heure.* Éditions de l'Observatoire / Humensis ■ Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2021). City Deal Ruimte voor Lopen. *Staatskrant, Nr. 4664, 2 Februari 2021.* Ministerie van Binnenlandse Zaken en Koninkrijksrelaties ■ Departement Omgeving. (2018). *Planning Beleidsplan Ruimte Vlaanderen. Strategische visie.* Departement Omgeving: Afdeling Beleidsontwikkeling en Juridische Ondersteuning.





Right-top: Workshop 'De Branderij', Amsterdam Centre: craft and creativity in a former coffee-roasting house, nestled in the inner city that earlier functioned as a 15-minute neighbourhood. Since 1976, the workshop – founded by carpenters and furniture makers displaced by metro construction in the Nieuwmarkt district – was combined with housing, in an area where most daily needs are just around the corner. [© Maurice Harteveld]

Right-bottom: Bosrankstraat, Buiksloterham Amsterdam North: here, infrastructure has been intentionally scaled down and integrated with hybrid programmes, including home offices, co-working spaces, and a training centre, on a former industrial site. Since 2011, residents have built their homes through collective self-build initiatives, designing their own car-light, green street: a made-to-measure living environment. [© Maurice Harteveld]

SYNTHESIS

ALIGN INDIVIDUAL STAKES INTO VALUE FOR ALL





Vlissingen, Zeeland: where the North Sea and the Scheldt River meet. Flood defence and boulevard with the Spuikom area at the back. [© Rijkswaterstaat, Joop van Houdt] **/ Coosje Buskenstraat – 'a street as river' – as one of the interventions for discharging overtopped water from the boulevard in the direction of the Spuikom.** [© Marije Verlinde]

SPUIKOM VLISSINGEN

A PARADIGM SHIFT FOR FLOOD RISK MANAGEMENT AND DESIGN

Traditionally flood risk management is focused on reducing the probability of flood by keeping water outside the built environment through the implementation of engineering solutions for protecting lives, goods, and property. What if this method leads to limitations? Should we try to stretch possibilities or explore another avenue? Can spatial design extend the space for solutions?

Delta Urbanism is a discourse from an integrated infrastructure design perspective to deal with flood risk, which contributes to the challenges in deltaic areas, as low-lying land at the interplay of soil and water. Delta Urbanism brings engineering, planning and governance together to create a future in which the development of deltas anticipates the natural dynamics. Currently, the knowledge of specialists working in deltas is within the paradigm of controlling the natural dynamics. Another form of collaboration is needed to secure the transformation of working protocols – supported by new instruments and methodologies – which aim for knowledge and goal integration. We should aim for a new approach of nature-inclusive design and engineering, in which nature is not brought under control but nature contributes to flood risk reduction. The aim is to enhance the inclusion of diverse perspectives of specialists working in the delta by use of interdisciplinary design to enable working with the natural dynamics as a condition for a sustainable future.

Central to flood risk management is the protection from and reduction of the impacts of flooding on people (including health and life), the economy, cultural heritage, and the environment (Priest et al., 2016). When moving to an interdisciplinary perspective, the central question is how the risk approach (Risk = Probability • Consequences) can be understood spatially, not only looking at casualties and damage, but how probability and consequence reduction can be achieved by spatial design. The new flood risk approach taken by the municipality of Vlissingen is exemplary to show the practicalities of the paradigm shift to working with nature[1]. The interdisciplinary design aimed at seeking a nature-based solution that would reduce the consequences of a flood, instead of reducing the probability of a flood occurring by simply raising the dike. [Risk Assessment, page 198]

In this contribution the Spuikom in Vlissingen is discussed to show the practicalities of the paradigm shift in flood risk management by an interdisciplinary design approach[2]. The approach starts with the phase of analysis from a spatial and engineering viewpoint, followed by interchanging spatial design and modelling. The result is a design for the Spuikom, a former water inlet and land reclamation site, which aims at reduction of urban flooding consequences instead of raising the dike to reduce the probability. The project shows how design with a long-term perspective can integrate the risk approach with spatial approaches.

Framework for an integrated and interdisciplinary approach

Three approaches are used in the integrated infrastructure design for the Spuikom: the vulnerability approach, the multi-layered safety approach, and the Dutch layer approach. All these approaches work with layers, the first two from a delta management perspective, and the last one from a spatial planning perspective. The factor 'consequences' in the risk approach is connected to the idea of vulnerability; its reduction is a valuable connection to spatial factors and measures. Vulnerability means the degree to which social and physical systems at risk can withstand damage and are able to return to their original state or even improve their performance. The primary aim is to create a resilient and healthy living environment by integrating all options to reduce vulnerability as a coherent approach (Adger & Kelly, 1999).

The vulnerability approach gives insight in how to understand the vulnerability of deltas by connecting it to four key capacities (De Graaf, 2009):

1. *Threshold*: holding the line and reducing the probability of a flood.
2. *Coping*: during an event, evacuation and other measures to reduce the consequences of a flood (minimized damage) due to resiliency.
3. *Recovery*: how easy it is to rebuild after the storm (robustness) and the costs of rebuilding can be reduced.
4. *Adaptability*: the capacity to anticipate coherently on future developments and risks.

In Dutch flood risk policy, the multi-layered safety approach was the first step away from the traditional risk approach that focused on reducing probability (Rijkswaterstaat, 2009). There are three layers:

1. *First layer*: focuses on threshold capacity and keeping the line of defence.
2. *Second layer*: involves reducing vulnerability through spatial planning tools and building codes to enhance all three capacities of coping, recovery, and adaptability.
3. *Third layer*: centres on crisis management, represented by recovery capacity.

This reasoning in layers is connected to the Dutch layer approach that was developed ten years prior with the aim to understand spatial organization and to prioritise spatial claims and interests based on any project's spatial dynamics and environmental robustness (De Hoog et al., 1998). Here, three layers are presented:

1. *Substratum layer*: the natural system, which develops over the long term and with low dynamic.
2. *Networks layer*: the infrastructure to manage the substratum, characterised by a shorter term and a higher dynamic.
3. *Occupation layer*: how humans live within the conditions set by the former layers. This layer has the highest dynamic and the shortest term of change.

Because each of these layers transforms over different time scales, the prioritisation should lay with the slowest layer of substratum. Time as such is a critical factor in spatial planning and design, which also enables designing for a longer time span to enable decision-making over time, instead of a short period. This facilitates negotiations between areas with low and high dynamics in spatial development and can be related to changes in the system that can be predicted, like sea level rise. [Layer Approach, page 94]

The connection between the three approaches, as was also investigated for the case of Galveston, Texas (Hooimeijer et al., 2022), is translated towards an application for spatial interventions (Table 1) which is considered key to the interdisciplinary, and thus integrated, design process. According to Hooimeijer et al. (2022): "The risk approach by reducing consequences considers a broader flood defence system (more than just reducing probability) as well as the dikes and the urban area behind the dike that are impacted. By increasing safety measures in the urban fabric, such as improving evacuation routes or raising the ground level of buildings, there should be a reduction in the number of casualties and/or economic damage". This contributes to reducing the overall consequences of a flood and could lead to a reduction of overall flood risk (Nillesen & Kok, 2015). It also gives the possibility to integrate designs for the reduction of consequences with other ambitions that are part of spatial development. [Flood Defences, page 280] [Benefit-Oriented Design, page 276]

Spuikom Vlissingen as an icon of the new paradigm

Vlissingen is situated in the Scheldt estuary, where the North Sea and the Scheldt River meet. This area has a high risk of flooding because of the funnel shape of the estuary. Since the shipping route from

Risk	Approach	Aspect	Spatial intervention
Probability	vulnerability approach (De Graaf, (2009)	threshold	dike dam gate sluice
	multi-layered safety approach (RWS, 2009)	first layer	
	Dutch layer approach (De Hoog et al., 1998)	substratum infrastructure	focus on construction of strength of barrier
Consequences	vulnerability approach (De Graaf, 2009)	coping – recovery adaptation	amphibious floating architecture space for water
	multi-layered safety approach (RWS, 2009)	second and third layer	
	Dutch layer approach (De Hoog et al., 1998)	substratum occupation	focus on timing and amount of water (inundation depth, discharge over time) participation with the natural system

Table 1. Relationship between the risk equation, flood protection approaches, and spatial interventions.

the North Sea to Antwerp passes by close by the shore, it is not possible to introduce a foreshore solution. The urban boulevard is situated on the main defence line, with a lot of hotels and a historical sea front. For the hotels the municipality implemented an innovative local building code which forces the hotels and flat buildings on top of the dike to accommodate future raising of the defence dike (Bekkering, 2024). This approach, known as 'Vlissings model', supports the traditional flood risk approach of maintaining the defence line, focusing on lowering the probability in the risk approach. These buildings replaced the historical frontline buildings and blocked the natural connection to the sea. As a result, the municipality wanted to explore an alternative approach to the traditional method of protection and investigate how to mitigate the consequences by accepting overtopping. This led to the Spuikom model. This model anticipates urban development by creating space behind the defence line in a former sluice system area – known as Spuikom – to store overtopping water (Figure 1).

The Spuikom model introduces an adaptive capacity of the area behind the dike while maintaining part of the threshold capacity. The integration of detailed and spatially explicit hydraulic models supported design decisions (e.g., the location of mobile barriers, the layout of new development, etc.). This does not come easily and requires a close collaboration between spatial designers and hydraulic engineers. The hydraulic models help to understand the flood events and calculate the amount and the location of water coming over the dike to make spatial design decisions. They also then assess the spatial intervention on its effectiveness within the time frame of a flood event (Hooimeijer et al., 2022).

The Vlissingen model considers the earlier approaches, but addresses only the threshold capacity explicitly – the first layer of defence – and combines the first and second layers of infrastructure and occupation by including private property as a part of the flood defence strategy. The Spuikom model is a step in shifting the paradigm in which flood defence becomes part of spatial (urban) design and entails working with local resources of the urban area and its ecological, touristic, and residential functions.

Interdisciplinary design as strategy – The applied interdisciplinary design approach was built on integrating conditions and an integrating research by design process. The conditions include five elements: (a) mutual exchange, (b) mutual influence, (c) goal integration, (d) basic integration, (e) managed integration (De Boer et al., 2006). The goal integration for this project was clear because the aim was to create a nature-based solution and the concept of not raising the dike was taken as a

starting point. The goal for spatial design was the revitalisation of the Spuikom area and the goal for hydraulic engineering was safety from flooding. There was a high degree of mutual exchange during this phase (activities of influence) and this resulted in mutual influence (reciprocal interaction and adaptation), basic integration (coexistence and basic coordination) and managed integration (initiative-taking planning, oversight, and mechanisms of collaboration and mutual benefit). The goal and its managed integration were secured in the interdisciplinary design process. This included three project phases: 1) analysis & synthesis, 2) design-stage simulation, evaluation, and decision, 3) delivery of the project and conclusions (Table 2). Each of the three phases has a disciplinary diverge part and interdisciplinary converge part. The design process started with the analysis & synthesis phase in which both spatial designers and hydraulic engineers used their disciplinary tools to understand the territory. The synthesis and integration of the work in the converge step led to the preparations for the design phase. In this phase the area was redesigned from both perspectives to perform within the shared design goal.

Hydraulic modelling of the Spuikom and its stress test under different conditions – The local situation is modelled with software called Hydra-NL, a probabilistic model that calculates the statistics of the hydraulic loads (water level, wave conditions, wave overtopping) for the assessment of the primary dikes and structures in the Netherlands (Rijkswaterstaat, 2019). Firstly, the larger area of Vlissingen was entered into the model to understand the larger scale of a flooding. Based on the results, it became clear that the focus should lie on the dike in front of the Spuikom area and that neighbouring areas would be excluded from this study. The first main conclusion was that this way of managing risk and reducing consequences should be done bottom up (per dike part) and not top down (dike ring) usually the case in the approach of reducing the probability by a risk reduction strategy.

The modelling thus continued only for the dike part of the Vlissingen sea front that would overtop during a storm to the Spuikom. The redesign of the basin had to attain a sufficient capacity and function as a buffer zone to allow the nearby canal to drain excess water over a longer period. This could be achieved by digging the bottom of two available Spuikom areas (S1 and S2) to an average elevation of +0 m and raising their edges to +4.96 m above NAP elevation (Figure 2). The Watergang channel located north of the Spuikom is used to drain excess water by means of a weir.

The next step was to model the calculated amount of water coming over the dike and ending up in the basins, for a moderate and warm+ scenario each for a 1:10,000 and 1:100,000 chance of occurring. These scenarios are based on different assumptions regarding global temperature rise (Vellinga et al., 2009). In the moderate scenario the hydrodynamic model calculates 78,400 cubic metres, while the warm+ scenario would entail 267,200 cubic metres of excess water to flood the Spuikom at the peak of the storm (Figures 3–6). The recovery of additional storage capacity makes it possible to achieve a retention capacity for the Spuikom of 186,000 cubic metres (140,000 m^3 for S2 and 46,000 m^3 for S1). For the warm+ scenario the remainder (89,000 m^3) can be managed by draining into the canal. With an outflow of 5 m^3/s generated by a pump installed at the opposite end of the channel, up to 18,000 cubic metres can be drained over the storm duration. The remaining 71,000 cubic metres can be stored in the channel itself, resulting in an increase in average water level of 0.41 m.

Based on the modelling of the event it became clear that there are five ‘holes’ in the dike through which the water could be conveyed to the Spuikom. The redesign of the Spuikom requires the excavation of around 15,400 cubic metres in S1 and of 18,800 cubic metres in S2. On the other hand, 8,500 m^3 cubic metres of earth are needed to raise the embankments of S2 to a minimum height of 2.5 m. In this case the damage is limited and mostly affect the buildings and roads behind the boulevard, resulting in 8.6 million euros of damage and 42 affected inhabitants. Based on the results of the social cost-benefit analyses (SCBA) in the project, the Spuikom model

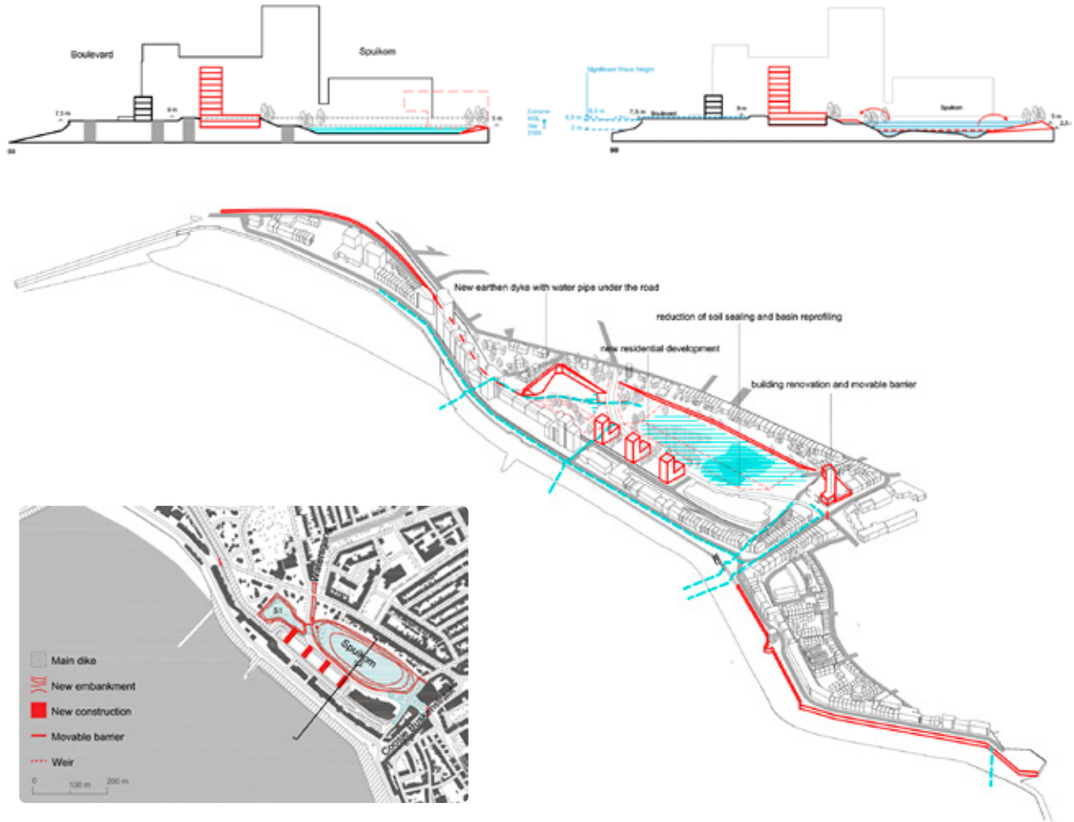


Figure 1. The Spuikom model, making space for water (with estimated still water level at 2,100 with 100,000 years return period. / Figure 2. Location of the basins in the area and cross-sections (top) to understand the flood over time of the event, in relation to the inundation depth. [Drawings: Andrea Bortolotti]

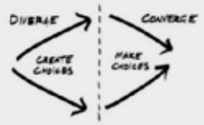
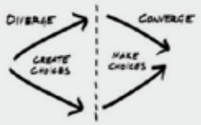
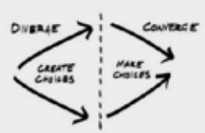
Analysis & Synthesis		Design		Delivery	
					
disciplinary	interdisciplinary	disciplinary	interdisciplinary	disciplinary	interdisciplinary
spatial analysis	synthesis of the analysed and problem definition	define spatial solutions (capacity of Spuikom)	solution definition, testing and projection	working out the spatial design	conclusions and developed integrated design set out in time
hydraulic modelling		simulations, technical interventions		detailing interventions	

Table 2. Phases of the interdisciplinary design process.

with these interventions creates more societal value on a larger scale but creates a smaller risk and is more economically efficient than the Vlissingen model, which shows the conventional grey infrastructure measure (Hooimeijer et al., 2022). [Social Cost-Benefit Analysis, page 200]

Street as a river – The Coosje Buskenstraat, a connection between the city centre and the boulevard of Vlissingen on the urban side of the Spuikom, has been included in the overall integrated design. The design on this level introduced the 'street as a river' concept[3] (see page 208). The design of the street posed two challenges: how to slow down the water and how to make the seawater flow in a 90-degree angle. Both were possible by slowing down the water and by steering it. The solution makes the street bulge so that the water is conveyed to the sides. In addition, parking spaces were staggered in relation to the parking spaces on the other side of the street and diagonal bands were created with openings to guide the water to the green strip as much as possible. The remaining water bounces off the raised edges of the green areas and continues its way in a slowed and meandering way. A physical barrier is still needed at the end of the street, at the intersection. That could be a removable barrier, but because it will only become relevant after 2050, there is still time to work it out further.

The design included the quality improvement that was desired. Before, this was a street with a lot of stone and paving, many parked cars, and no greenery. Now, it is a street where fewer cars can park and where there are fewer paved surfaces. Especially at the top, a large number of natural beds has been constructed and a green strip with trees has been added on both sides. Furthermore, the redesign in the choice of materials is in line with the goal of connecting the street more closely with the city centre. After being informed about its purpose and creating awareness that the risk of flooding would only become relevant after 2050, the residents reacted enthusiastically to the redesign (Bekkering, 2024).

Implementation of the research results in policy

The outcome of the project has been developed towards a new vision for the area. The municipality uses the street as a river concept to enter discussions with the water board Scheldestromen. It has been involved from the beginning and the water board has granted a water permit for this concept. It was an advantage that the risk was not yet current, so another strategy and design could be applied for its reduction. In terms of content, the water board found it an innovative solution. Based on this, the municipal council could adopt the Spuikom vision for the area around the old sluice basin. This included converting a parking lot into a car park with housing on top. The Vlissingen model has been applied as a part of the Spuikom model by integrating the car park into the plan; this will eventually be moved underground when it is necessary to raise the entire area to a new level in the future after the dike reinforcement (Bekkering, 2024).

The integrated design purpose of making Vlissingen safe by reducing the consequences of flooding (instead of reducing the probability) steered the study as a design and planning process into the context of a historical urban area, where the built and natural environment are part of a defence system. The flood defence infrastructure is not adapted to rising sea levels but instead the strategy aims to accept water in the proposition of the Spuikom model. The outcome of the study is to understand how acceptance of overtopping in the context of the Spuikom area creates flood defence on the local scale, and how this could be integrated with the creation of spatial quality in street and public space design, preservation of heritage, and real estate development.

Buying time with no-regret measures – The study resulted in the underpinning of a new approach towards risk mitigation by the innovation of the design and interdisciplinary design process. On the side of innovation, the project created insight in how to design for the reduction of consequences over time. Time scales were particularly important for design and for the municipality to make the decision to follow the chosen approach and to monitor developments (Figure 7). Because of the

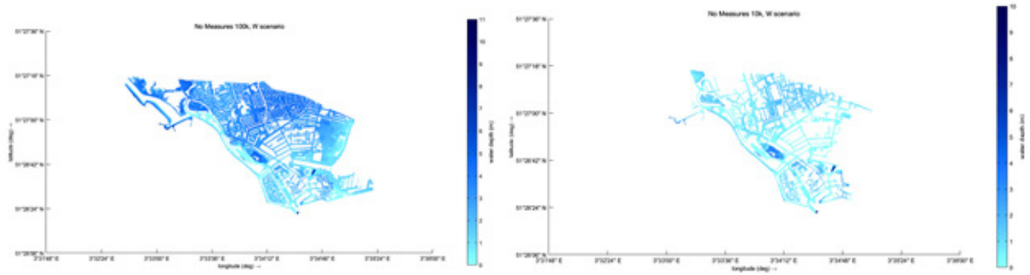


Figure 3. Warm+ scenario for the whole area with a return period of 1:100,000 and 1:10,000.

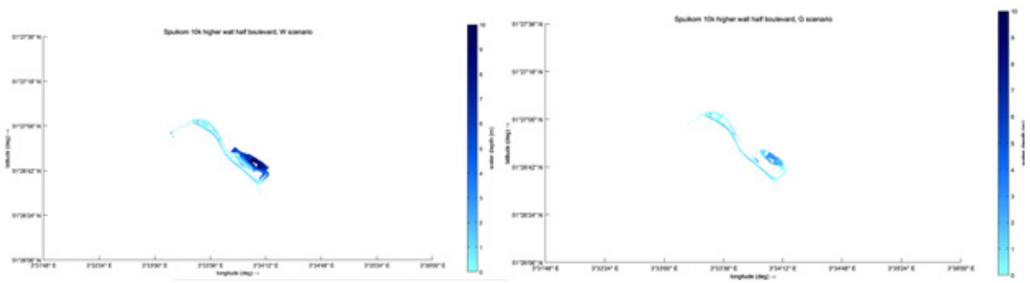


Figure 4. Warm+ scenario, risk 1:10,000, total 267,200 m³ water. / Figure 5. Moderate scenario, risk 1:10,000, total 78,400 m³ water.

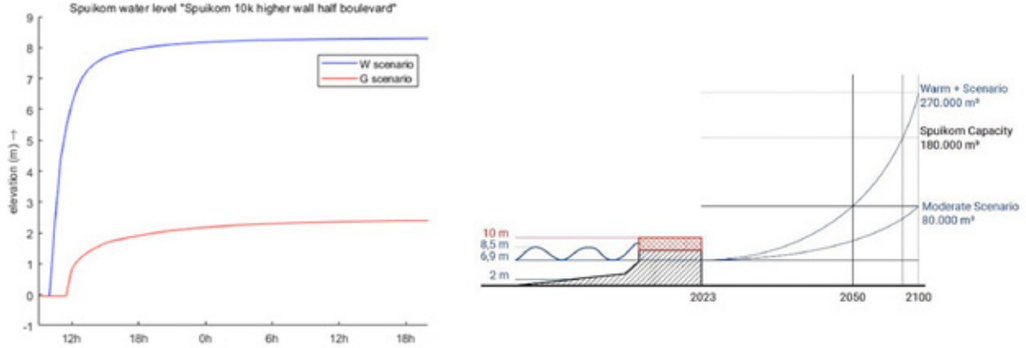


Figure 6. Graph of both the moderate and warm+ scenarios over the time of the event. / Figure 7. Timeline of decision-making. [Images: Andres Diaz Loaiza]

combination of scenarios (moderate and warm+) over time (to 2100) – based on the careful spatial study of the area (levels, urban constructions, etc.) and the calculation of the amount of flood water in cubic metres (instead of inundation) – it was possible to design a strategy that can be adapted over time. It enables *no-regret decision-making* (all decisions are valuable for the future, no matter what scenario) for the near future with options for adaptation in the future. Acceptation of the overtopping of water in a storm, in combination with adaptation of the Spuikom to steer water, is a valid solution when climate change turns out to be moderate. When climate change will follow the warm+ scenario, this solution will work until around 2090. After that, either the solution of the Watergang channel needs to be executed or another decision can be made. The municipality can foresee this decision decades before it actually happens.

The results of the project were used as the basis for the Spuikom vision, in which functionality, performance, intervention scales, spatial quality and collaboration were decided on and formulated.

Besides the zone being part of the flood risk management approach, which makes the area resilient to storms, it can function as a high-quality housing area and park. The vision captures all these ambitions together by participating in the research project SARCC with a focus on interdisciplinary design, and at the same time work with communities in a transdisciplinary setting. [Integrated Infrastructure Design Lenses, page 182]

Can we speak of a new paradigm?

The results of the project reflect the Delta Urbanism approach that brings engineering, planning and governance together in a paradigm shift, in which the development of deltas is anticipating the natural dynamics. The paradigm shift is characterised by moving the risk reduction away from reduction of the probability of a flood, to the reduction of the consequences in flood risk management. This can only be done by making hydraulic engineering modelling a crucial aspect of the design process. The hydraulic model can confirm the technical feasibility of the design strategies for flooding in future climate scenarios. The combination of the hydraulic model with land use maps allows for calculating flood patterns and creates space for societal benefits in the longer term. The major impact of the new paradigm which focuses on the reduction of consequences is that the line of defence becomes a zone in which many more variables and stakeholders take part. It becomes much more complex, so that a qualitative evaluation should inform decision-making for political approval and social acceptance.

Fransje Hooimeijer, TU Delft

Notes

1. The Vlissingen project was part of Sustainable and Resilient Coastal Cities (SARCC), a European Interreg-Two Seas project (https://www.interreg2seas.eu/en/SARCC). In this project the delta urbanism and the hydraulic structures groups of TU Delft collaborated with partners from seven municipalities, among which Vlissingen, and other research partners in France, England, Belgium and the Netherlands, with the aim to realise nature-based solutions for the protection of coastal cities.

2. This contribution is based on results of the collaboration in the SARCC research by the members of the TU Delft team: Andres Diaz Loaiza, Andrea Bortolotti, Qian Ke, Jeremy Bricker, Luca Lluorio and Fransje Hooimeijer.

3. This was developed and designed in collaboration with Ferry Kramer, the water manager of the municipality of Vlissingen.

REFERENCES ■ Adger, W. N., & Kelly, P. M. (1999). Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change 4*(3-4), 253-266 ■ Bekkering, P. (2024). Vlissingen richt straat in als rivier, accepteren dat bij extreme stormen zeewater over de zeewering komt. *Stedenbouw en Architectuur, 41* (2) ■ De Boer Y., De Gier, A., Verschuur, M., & De Wit, B. (2006). *Researchers on their experiences with interdisciplinary research in the Netherlands.* RMNO, KNAW, NWO, COS ■ De Graaf, R. E. (2009). *Innovations in urban water management to reduce the vulnerability of cities: feasibility, case studies and governance.* Delft University Press ■ De Hoog, M., Sijmons, D., & Verschuuren, S. (1998). Herontwerp van het Laagland. In D.H. Frieling et al. (eds.), *Het Metropolitane Debat* (74–87). THOTH ■ Edmonds, D., Caldwell, R., Baumgardner, S., Paola, C., Roy, S., Nelson, A., & Nienhuis, J. (2017). A global analysis of human habitation on river deltas. *19th EGU General Assembly, EGU2017, proceedings from the conference held 23-28 April, 2017 in Vienna, Austria,* 10832 ■ Hooimeijer F.L, Diaz, A., Bortolotti, A., Ke, Q., Van der Heuvel, J., & Bricker, J. (2022). Design & assessing the flood risk management paradigm shift: an interdisciplinary study of Vlissingen, the Netherlands. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 17*(4), 555-576 ■ Nillesen, A.L., & Kok, M. (2015). An integrated approach to flood risk management and spatial quality for a Netherland's river polder area. *Mitigation and Adaptation Strategies for Global Change, 20*(6), 949–966 ■ Priest, S.J., Suykens, C., Van Rijswick, H. F. M. W., Schellenberger, T., Goytia, S., & Kundzewicz, Z. W. (2016). The European Union approach to flood risk management and improving societal resilience: lessons from the implementation of the Floods Directive in six European countries. *Ecology and Society,* 21(4) ■ Rijkswaterstaat (RWS). (2009). *Nationaal Waterplan 2009-2015.* Ministry of Infrastructure and Water Management ■ Rijkswaterstaat. (2019). *HydraNL – Gebruikershandleiding.* HKV consultants ■ Vellinga, P., Katsman, C., Sterl, A., Beersma J., Hazeleger, W., Church, J., Kopp, R., Kroon, D., Oppenheimer, M., Plag, H., Rahmstorf, S., Lowe, J., Ridley, J., Von Storch, H., Vaughan, D., Van de Wal, R., Weisse, R., Kwadijk,J., Lammersen, R. & Marinova, N. (2009). *Exploring high-end climate change scenarios for flood protection of the Netherlands.* KNMI scientific reports.

LESSONS

A PARADIGM SHIFT FOR FLOOD RISK MANAGEMENT AND DESIGN

When looking back at this approach, its phases and processes, results and outcomes, we can distil the following lessons:

- ***Integration by an interdisciplinary approach and collaboration.*** The applied framework of different but interrelated approaches makes clear that an integrative and interdisciplinary approach is essential for a common understanding of the problem definition, shared fact-finding, conceptualisation of the solution space, and applied design strategies.

- ***Understand the water system.*** Reducing the consequences of a flood as part of a risk approach is possible in area development by integrating knowledge, data, and insights of the particular water system, but it needs to be overseen on local (dike section) scale.

- ***Use appropriate hydraulic models.*** Simulation models of the water system do not have to be too detailed for area development. They must calculate and represent water volumes and not only inundation. It is necessary to define the sections of the infrastructure which are most vulnerable and with limited possibilities to reinforce, and areas with potential retention capacity.

- ***Interdisciplinarity is key for innovative concepts.*** As the starting point of a leading concept, a nature-based solution works well in an interdisciplinary design setting because it makes for a shared goal.

- ***Multifunctional design adds value.*** The implementation of the water-integrated street design proves that it positively affects spatial quality because it is combined with a green structure.

- ***Stimulate best practices.*** We need more pioneering designs like the Spuikom model to be able to understand a general shift in flood risk management and integrated design perspectives.

- ***Collective learning innovates.*** For a municipality the participation in research trajectories is a possibility to find out-of-the-box solutions.

- ***Transdisciplinarity pathways to the future.*** The approach of the problem should be done from an integrated perspective, not just urban planning and design or just water safety issues. Challenges, including climate change, go beyond disciplines. This may be less efficient than an approach per sector, but it creates added value on the longer term.



INNOVATIVE FLOOD PROTECTION WORKS CONSIDERING ECOLOGY AND LANDSCAPE

The Oosterscheldekering, a moveable storm surge barrier for the Eastern Scheldt estuary, allows for tidal movements in the estuary but protects against floods when necessary. This governmental and engineering challenge sparked by social protest addresses environmental and economic values. Where do we stand now? What could we expect for the future?

CHARACTERISTICS

The Oosterscheldekering, opened in 1986, connects the islands of Schouwen-Duiveland and Noord-Beveland on the two sides of the Eastern Scheldt, which flows into the North Sea. The Eastern Scheldt forms a critical natural and economic zone, with a diverse marine ecosystem and a rich fishing tradition. The barrier is the largest and most extensive storm surge barrier in the Netherlands – part of a comprehensive system of dams and barriers constructed in response to the devasting 1953 flood – to protect the Netherlands from flooding. It is widely regarded as the crown jewel of the Delta Works and globally recognised as an iconic landmark in hydraulic engineering.

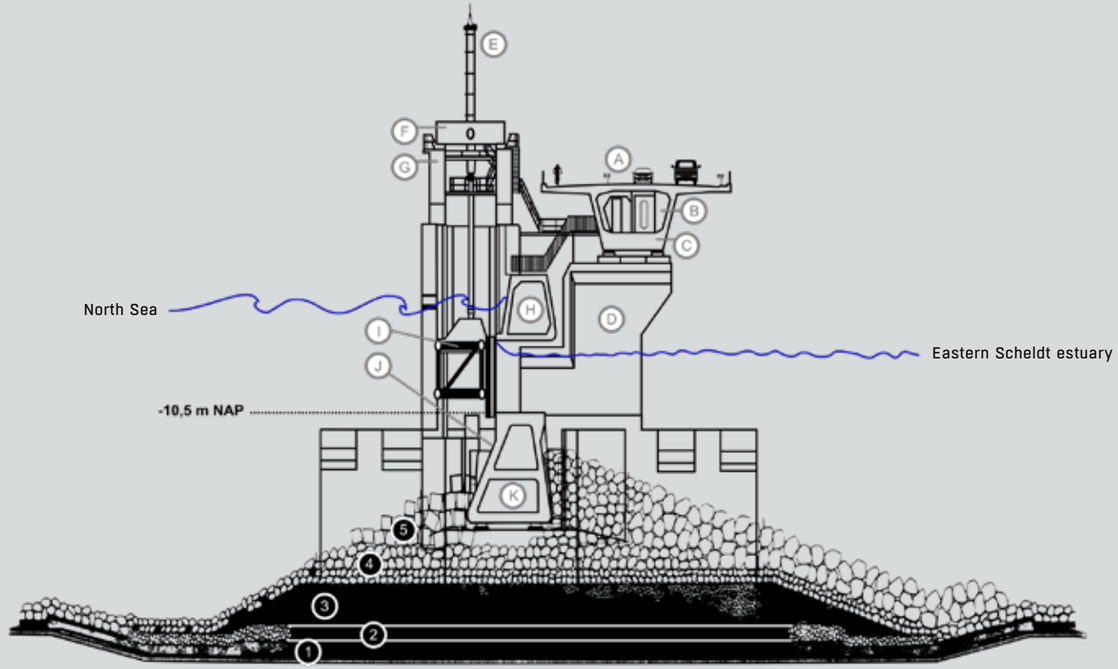
The barrier protects the southwestern Netherlands from sea storm surges while preserving the natural tidal movement and saltwater environment of the Eastern Scheldt estuary. It represents a compromise between safety and ecology, maintaining the diversity of the estuarine ecosystem – while providing a high safety level of flood protection to hundreds of thousands of residents and major agricultural areas in Zeeland. Furthermore, it is part of the national transportation network (carrying the N57 motorway) and shortens the route from north to south by approximately 60 km.

Originally, a closed dam was planned that would permanently seal off the estuary from the sea. However, after widespread public protest from environmentalists, fishermen, attorneys, and scientists, the design was adapted to allow partial flow exchange. The result was a combined solution: approximately 6 km of closed dams and 3 km of storm surge barrier. The barrier was divided into three sections that consist of a series of massive piers and gates that remain open under normal sea conditions, allowing water and marine life to pass through. When sea levels rise – typically when a rise above NAP + 3.0 m is forecast – the gates are lowered to seal off the estuary protecting the inland from sea flooding. The barrier is designed to close once a year on average, and to withstand a sea water level that statistically occurs once in every 4,000 years. It consists of: (a) 65 concrete piers, each between 30 and 40 metres high and weighing up to 18,000 tons; (b) 62 steel moveable gates, each 42 metres wide and 6 to 12 m high, and weighing between 260 and 480 tonnes, which can be lowered to prevent storm surges.

SIGNIFICANCE

From an engineering perspective the barrier is an unparalleled feat of civil engineering even under present technology. Advanced engineering techniques were used, including compaction of the sandy subsoil, the use of artificial islands and pre-cast concrete units. The massive concrete piers were built on land in a dry building dock and floated out. Special vessels and custom-built construction equipment were used to place the piers with millimetre precision, using advanced dredging and hydraulic engineering methods. It combines various functions, i.e. flood defence, maintaining marine ecology, road traffic, and navigation. From an environmental perspective – unlike closed dams – the barrier was designed to maintain the natural saltwater ecosystem by the partially 'open' estuary, crucial for

Previous pages: the Oosterscheldekering with closed gates during storm from the sea side. [© Rijkswaterstaat, Rens Jacobs]



Cross-section of a movable gate compartment of the Oosterscheldekering, here using the example of pier Roompot 12. Note: the horizontal extent of the foundation layers is shown compressed and therefore not to scale with the vertical extent of the graphic. Foundation layers: stone layer (10-60 kg), (2) stone layer (60-300 kg), (3) stone layer (300-1000 kg), (4) stone layer (1-3 t), (5) concrete blocks (2 m³). Components of the structure: (A) road, (B) cable tunnel, (C) hollow road girder with drive mechanism, (D) pier, (E) hydraulic cylinder, (F) beam for the suspension of the contactors, (G) pier attachment, (H) yoke beam, (I) contactor, (J) sleeper beam, (K) sand ballast. [CC Alabasterstein]





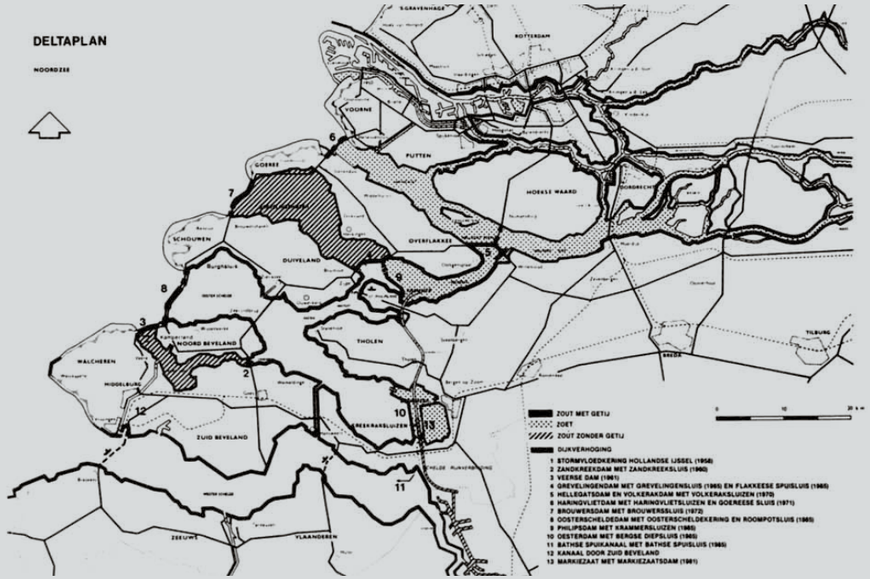
Left: building site for piers. [© Rijkswaterstaat, Harry van Reeken] **/ Right: map of the Oosterscheldekering with the artificial island Neeltje Jans and the motorway N57. On the south side, the connection is shown with Noord-Beveland with the Roompot barrier; on the north side the connection with Schouwen-Duiveland with the Hammen and Schaar van Roggeplaat barriers.** [CC Alabasterstein]

biodiversity, fisheries, and aquaculture. The barrier is also a major tourist attraction with cultural and educational value. It has a visitor centre, Deltapark at Neeltje Jans – an artificial island – offering educational programmes and exhibitions about the Dutch flood protection history, Dutch Delta Works, climate change, and future challenges. The barrier is of economic importance with local and regional benefits. It protects critical agricultural lands, transportation networks, and residential areas while supporting fishing, shellfish and oyster farming – key to the economy of the province of Zeeland. While the barrier is undoubtedly an engineering achievement and has successfully protected large parts of the Netherlands from flooding, its construction and operation have led to considerable challenges, particularly in terms of minimising environmental impact related to the sediment balance, managing operational and maintenance costs, and ensuring long-term functionality in the face of accelerating sea level rise and structural ageing. Although the gates and piers were engineered with an additional safety margin, they are not infinitely scalable. After approximately 1.3 meters of sea level rise, the barrier would require major reinforcements or would need to be closed more frequently, which, in turn, would more often disrupt the tidal ecosystem within the estuary.

Cong Mai Van, TU Delft

LOCATION: Eastern Scheldt estuary, Zeeland ■ **CLIENT:** Rijkswaterstaat, Ministry of Infrastructure and Water Management ■ **PLANNING/DESIGN:** Ministry of Transport, Public Works and Water Management ■ **DESIGN/ENGINEERING/CONSTRUCTION:** DOSBOUW and Dijksbouw Oosterschelde consortia (Ballast Nedam, Boskalis Westminster, Baggermaatschappij Breejenhout, Hollandse Aanneming Maatschappij, Hollandse Beton Maatschappij, Van Oord-Utrecht, Stevin Baggeren, Stevin Beton en Waterbouw, Adriaan Volker Baggermaatschappij, Adriaan Volker Beton en Waterbouw and Aannemerscombinatie Zinkwerken) ■ **REALISATION PERIOD:** 1976-1987.

FURTHER READING ■ Ministry of Transport, Public Works and Water Management. (1994). *Design plan Oosterschelde Storm-surge barrier. Overall design and design philosophy.* A.A. Balkema ■ Van Heezik, A. (2011). *De Kering. Over de bouwers van de stormvloedkering Oosterschelde.* Veen Magazines ■ Steenhuis, M. (2016). *De Deltawerken.* nai010.



Map of the Delta plan for the flood protection of the southwestern region of Netherlands, used for reporting on the progress of the Delta Works. [PD House of Representatives of the Netherlands]

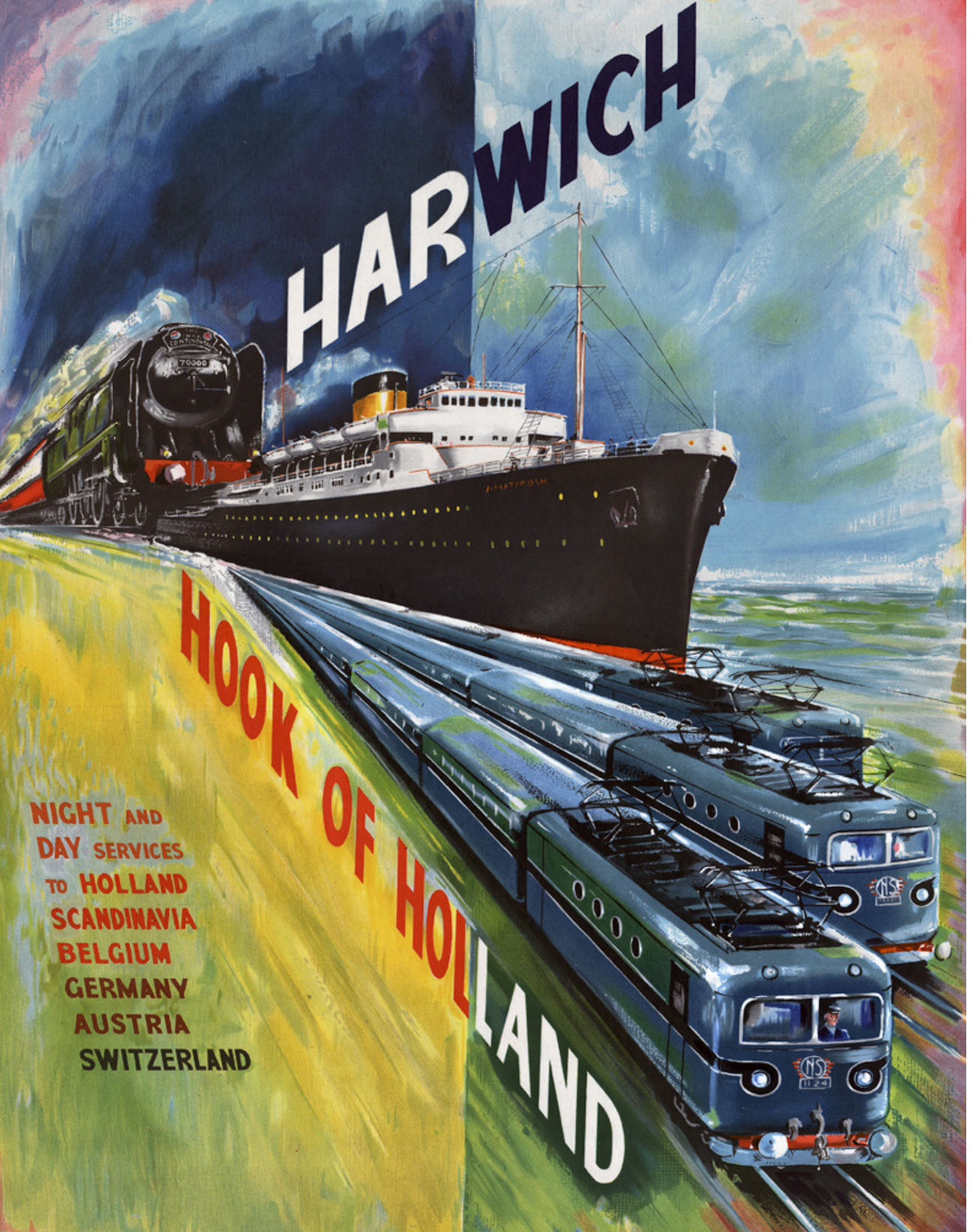




The Ostrea, a dedicated vessel for lifting and positioning piers to their location. / Placement of a traffic shaft for road support, housing the drive and control equipment for the gates. [© Rijkswaterstaat] / Below: piers and gates and traffic shaft with the road on top. [© Rijkswaterstaat, Harry van Reeken] / Roompot ship lock for recreational boats with the N57 motorway at the artificial island of Neeltje Jans. [© Rijkswaterstaat, Joop van Houdt] / Aerial view of the Oosterscheldekering as seen from Noord-Beveland with the Roompot barrier, Neeltje Jans, the Roompot ship lock and the former working ports Mattenhaven and Betonhaven. [© Siebe Swart]







Poster by Paul Mann, 1954. [Collection Arjan den Boer, retours.eu]

CONVERSION HOEKSE LIJN

EXPRESSIVE FUNCTIONALITY BY REMOUNTABLE DESIGN AND CONSTRUCTION

Until well into the last century, the Hoekse Lijn was part of the international railway connection between London and several European capitals. However, due to the rise of aviation and the commissioning of the Channel Tunnel, this connection fell into disuse and degraded to a local commuter train. By placing the connection in a regional perspective, the challenge was taken up to convert the railway into a metro line. What significance and value did architectural design have in this? Will this new metro bring a new boom for the line and the region?

In 1839, the first railway line in the Netherlands was put into operation between Haarlem and Amsterdam. In the years that followed, it was extended to Leiden, The Hague and in 1847 to Rotterdam. In the boom of construction of railway lines, the idea arose to give this railway line a branch to Maassluis. In 1875, the Dutch Parliament decided to build this branch, but then immediately extended it to Hoek van Holland – a visionary decision, as it turned out later. Hoek van Holland was created as a workers' village before the construction of the Nieuwe Waterweg, a waterway for the expansion of the port which was completed in 1872. The railway offered the opportunity to develop Hoek van Holland into a seaside resort and landing point for ferries to Harwich in Great Britain. This made it possible for train passengers to travel in luxury between London and Moscow, Berlin, or Prague, as several train service providers offered and advertised (Paul Mann, 1954; Figure 1). This international connection has always given the railway to Hoek van Holland, generally called Hoekse Lijn, a special dimension. Since the opening of the Channel Tunnel in 1994, international trains have increasingly disappeared. Between 1997 and 2007, Stena Line operated a passenger service between Hoek van Holland and Harwich with a high-speed ferry four times daily. When this boat connection to England was replaced by a conventional twice daily ferry, the intercity train, which ran as a boat train to and from Amsterdam, also disappeared. As a result, the Hoekse Lijn became more and more a local railway, mostly used by students and commuters who could not afford a car. However, for them, the journey by train was not really pleasant. Where the original train passengers could look from the railway embankment over a mainly open polder landscape, the horizon slowly but surely became fuller and fuller. On the south side, the Port of Rotterdam continued to expand. On the north side of the railway line, the Westland greenhouses turned into a continuous, high-productive 'flower and vegetable factory', which lit up the sky at night. In addition, the cities of Schiedam, Vlaardingen and Maassluis expanded to the railway line. To the train passenger, this variety of built-up environments felt like unwelcoming. Old harbour sheds, backs of houses, undefined parks and here and there a view of a historic square or football cage. A 'wonderful' collection of diversity, but around the stations there was certainly no 'self-organized urbanity'. It seemed as if the London-Moscow line had skipped this part of the world in its 130 years of existence. The train stations were isolated and somewhat lost in their surroundings, despite being located in a rapidly developing region.

A long time ago I was standing with architect Meinhard von Gerkan in a desolate area somewhere in Berlin. He was explaining with big gestures where the new Lehrter Bahnhof, a design by his hand, would be built. I asked him the naïve question whether the station, which would later be renamed Berlin Hauptbahnhof, had not been conceived in the wrong place. The emptiness around us made it clear that this was not the most dynamic place in Berlin. He looked at me somewhat surprised and spoke calmly but with full conviction: "Every station is automatically in the right place after 100 years". A station organizes its environment through time, was his message, a law that is visible at many stations. A similar development can be seen for the stations on Hoekse Lijn.



Figure 1. View of the platform of the Hoek van Holland Haven station with a boat train along the platform in 1959, and a destination board of the train service Hoek van Holland – Moskou. [PD Het Utrechs Archief, Nederlandse Spoorwegen]

The regional economic and transport authority for the Rotterdam – The Hague Metropolitan Region (MRDH) recognised the development potential of such dilapidated railway lines and developed an ambitious spatial policy in the 1990s in which existing infrastructures and networks would be better used as carriers of urban development. This was a huge task for the southern part of the Randstad, in terms of housing, work locations and high-quality recreational and nature areas.

The Hofpleinlijn between Rotterdam and The Hague and the Hoekse Lijn between Rotterdam and Hoek van Holland soon caught the eye (Figure 2). Both lines belong to the first generation of railway lines in the Netherlands. Old and somewhat worn, but with a lot of 'load capacity', they had the potential to serve many passengers. In 2002, the RandstadRail project was launched, including the conversion of the Hofpleinlijn to metro line E. For this conversion, most of the railway route was retained, renovated, and made suitable for metro operation. At both ends of the line, the route was adapted to better connect to the urban public transport networks of Rotterdam and The Hague. To fully exploit the potential of a fast and high frequency metro line between Rotterdam and The Hague, the existing train stations were converted into metro stations and new stations were added. In 2006, metro line E was put into operation. It was an immediate success. While the railway line had carried 7,000 passengers per day, the metro line reached approximately 54,000 passengers per day in 2019 (Kolkowski, 2023). In the years after the conversion, tens of thousands of homes were built around this line and the metro line is an important quality in the daily urban system of the people who live along the line and work, attend school or shop in Rotterdam or The Hague. It is therefore a textbook example of sustainable development in which an outdated railway line has been reused, and a metro line has become the carrier of urban development. After the completion of metro line E, the focus of MRDH shifted to the Hoekse Lijn. Would it be possible to convert this languishing railway line into a strong and meaningful carrier of urban development in this part of the region?

From ambition to vision

The ambition for the conversion of the original Hoekse Line into a metro line was to convert it to the daily urban system for the people who live and work along the line, or attract new inhabitants who want to live and work along the line because of better accessibility and faster travel times. This brought with it the realisation that the quality of living near a station on the Hoekse Lijn lies not only in the quality of that place itself, but also with which that place is connected. How quickly and comfortably can other destinations be reached? Living in an urban region is only interesting if the diversity of functions, activities and destinations in that region can be reached quickly and comfortably. The metro offers the opportunity to reach at many places in Greater Rotterdam without barriers within tens of minutes several times an hour. This not only brings work and school closer, but also going out, meeting others, recreation, and many other activities that give life meaning, and that make life in a city attractive. Thus, the conversion project had to lead to a great improvement



Figure 2. The Hofpleinlijn was the first railway line that was converted to a metro line, between Rotterdam and The Hague. The Hoekse Lijn has been converted between Schiedam and Hoek van Holland and integrated in the metro network of Rotterdam (black/white line). [PD Michiel1972]

in quality compared to the former train line, as well as a better connection of the area on the line to the urban network of Rotterdam and thus the southern part of the Randstad. This leap in quality should influence the *modal split* in favour of public transport and therefore also cycling and walking and enable further densification within the Randstad, so that the landscape can be spared. Conversely, it should be possible for inhabitants of Rotterdam to travel to this part of the urban countryside for work, social visits, training, or recreation.

How to translate a transport ambition into an architectural vision? – A transport ambition requires more than just a functional plan. Speed, reliability, safety, operation, financial coverage, management, maintenance are all important, of course. But it was clear to MRDH from the start that soft aspects, perhaps not strictly functional, would also be decisive for the success of the conversion of the Hoekse Lijn. The conversion of the Hofpleinlijn into metro line E had made it clear that the spatial layout around the stations and the experience of the stations were important success factors. What was the Hoekse Lijn conversion project, which also includes an extension to the beach at Hoek van Holland, really supposed to be about? A vision was needed beyond the level of 'stacking stones' was requested from two architects, Maarten Struijs, and the author of this contribution, both of whom have experience in the integral design of infrastructure. Both are employed as 'infratects' by the municipality of Rotterdam the Engineering Office (IBR) of the Rotterdam Department of Urban Development. Maarten Struijs was previously involved in the conversion of the Hofpleinlijn. [Infratecture, page 284]

How does a vision arise? Where do you start? With what is already there: there already is a railway, and trains are already running. Sitting in the train, bumping through the landscape, the landscape passes by. The train rides turned out to offer the ideal stillness for both architects to muse about that landscape. Seen from a standstill and a distance, a train runs through the familiar landscape every 30 minutes. Due to the rhythm of the timetable, the train is also part of that landscape permanence. From the train, the port can be viewed from a distance and understood in slowness. At the same time, the heron in the ditch along the track can only be seen in a flash. Big, distant, old, vague, human, new, young, animal, concrete, noise, silhouettes, fast, colourful, and slow are just a few of the terms that had to be brought together into an architectural vision based on fieldwork in the first hour. The dilapidation of the line was of course noticeable; the backs of the cities that passed by as well. This also applied to several train stations on the line, looking as if they were on the sidelines, ignored by society – almost in pause mode, waiting to be involved in the daily lives of local residents again. The architectural vision on the line had to be about the environment, about connection, about accessibility, about guidance, about the surrounding land, and about creating conditions for development. But the vision should also be able to be realised. Placing such an architectural vision too far outside the mind, based on the *sober and efficient* mantra so familiar to Dutch infrastructure projects, would lead to the risk that little or nothing would be

done with it. Conversely, a vision based solely on sober and efficient design will not elevate the project above a functional civil engineering exercise.

Erasmian Urbanism: Embracing of vagueness and slowness – You muse alone, in your head; a mental digression like daydreaming with the passing landscape as a slowly-changing backdrop. Sharing snippets of thoughts with your fellow architects leads to free associations, musings, and reflections. This process does not have to take long, but needs sufficient room. Interesting in this retrospective is the urban planning theory 'Erasmian Urbanism' that Maarten Struijs had formulated just before as a lecturer at Rotterdam University of Applied Sciences (Struijs, 2006). The essence of Erasmian Urbanism is the conviction that there is only a chance to create urban quality if plans are created in *vagueness* and *slowness*.

Vagueness gives room for different insights to come together; room for a plurality of opinions. Slowness prevents a plan from being created entirely in the spirit of one era, generation, or view that is already outdated at the time of realisation. Entirely in line with Erasmian Urbanism, we started to think in incomplete possibilities about an architectural vision that transcends disciplines, but at the same time will not be able to match the complexity of the reality of tens of thousands of lives, feelings, thoughts and actions. This complexity receives too little attention in the world of infrastructure. When I try to understand myself, I am unable to do so; and especially when I consider that my neighbour, my partner, my colleague, my children are all independently thinking people like me. Complex beings, with their own thoughts, desires, fears, and dreams. So, what is going on at the same time in the same place in a metro carriage somewhere on the Hoekse Lijn in the heads of all those passengers? Add to that the complexity of the people living and working in the vicinity of the line at that moment, and the challenge becomes even greater. This reminds me of a quote by Rem Koolhaas: *"Planning is not just the attempt to do something immediately, but an attempt to imagine or create conditions that allow different forms of density, or different scenarios to develop. Once you start to investigate that, you can be completely daunted by the task."* (Kwinter, 1996). One has to be impressed, to go deep, to strive for multiplicity, but to be satisfied with the realisation that completeness does not exist in the world of realisation of infrastructure, and therefore cannot be pursued. Of course it is worth striving for but not actually feasible, but we should be aware that the quality of a plan is largely determined by this. The overall ambition of the Hoekse Lijn project thus had to be completed with the awareness of incompleteness, in other words, in this complexity. The courage to be aware and perhaps even familiar with this complexity must lead to action, and so does the realisation that every form of action is only a weak substitute for the complexity from which it arises. Furthermore, it is certain that this complexity can also develop in all kinds of unforeseen directions in the future. The awareness of plurals must not oppress, narrow, or suffocate us, so that the step to action is not taken. The alternation of train journeys, walks, cycling, conversations, reading, musing, doubting, desktop research and continuous thinking laid the foundation for an architectural vision of the line.

From bolt to landscape – Recording an architectural vision in a document requires the transition from musing to daily reality. Laid down in the form of an ambition document, this vision mainly required room and attention for the traveller (Struijs, 2007). The traveller who wants to travel efficiently, comfortably, and pleasantly, who keeps his coat on in the metro, who travels from place to place, and who also makes a journey within himself. In the case of the Hoekse Lijn, there were already passengers: the train passengers. However, these train passengers would have to make way temporarily for the conversion activities. It is no small thing to close an existing and functioning railway line and thus disadvantage the passengers, who are used to using this line. Replacement bus transport is only a small compensation. A quick, short-term conversion is therefore essential.

Prior to the drafting of the ambition document, it was clear that the construction sites for the stations would only be available for three months, the period between the termination of train operation and the test phase of metro operation. This limited construction time immediately made it clear that traditional construction was not possible and that the stations could only be developed based on prefabrication and on-site assembly. After a tour of the existing train stations on the line and an analysis of the recently completed conversion of the Hofpleinlijn, the ambition document set out the ambition for the stations in ten starting points. This architectural vision, formulated somewhat staccato, immediately made clear that it was not about 'making buildings'. In fact, it was already established in this vision that the assignment covered a wide range of tasks, from detailed, prefabricated, industrially manufactured parts to interventions and additions to the scale of the landscape. Where Bakema *designed from chair to city* (Bakema, 1964), the Hoekse Lijn, like so many infrastructure projects, goes *from adjusting a bolt to designing a landscape*.

The architectural ambition emphasized the stations being recognizable, safe, welcoming and optimistic. A green setting was needed for the surroundings of the stations, so that they would take up a clear position in the surrounding neighbourhoods. A green environment should be not presented as a promise in drawings, but realised from the moment it opens. It should radiates peace and sustainability and therefore also reassure and offer comfort and confidence to the traveller. This ambition requires attention to a highly recognizable image, both during the day as well as at night. Even in the dark, a station must be clear and orderly and, as a beacon of light, it will have to add meaning to its urban environment. The ambition document already indicated that the stations must be the result of an integrated design process and that this must include prefabrication and assembly. The last point of the architectural vision reflects this:

"*For the stops of the new Hoekse Lijn, a 'broad' design team must be set up, in which an 'architectural' architect, an industrial designer, a lighting designer and an outdoor designer will take place. They must develop proposals as a team, not as four designers who make their own design next to each other. Taking a seat in this team, the differences between the disciplines disappear; only in this way can we arrive at integrated designs.*"

It should be clear that the formulated ambition was already firm about the process needed to achieve the intended integral quality. This could only be achieved by combining knowledge and skills from different disciplines. Perhaps an ambitious vision; and yet, for the client MRDH this was a vision that was so challenging and at the same time gave confidence, as an established ambition, that it forms the basis for the further project steps by the Engineering Office of the municipality of Rotterdam.

Coherence of design and construction method

To develop a concept design for the stations, the Engineering Office put together an integral design team. In addition to the usual architect, structural engineer and geo-engineer, for this assignment a steel expert, concrete expert, landscape architect and industrial designer were added to the design team. The design team translated the short construction time into the ambition to develop a *remountable* design, a form of sustainable construction in which the materials, parts and details are designed in such a way that each part can be removed from the building without damage. The material used thus retains value and is suitable for (high-quality) reuse after the first life phase. A design based on this principle has the advantage that the building elements can be manufactured prior to the available construction time (prefabrication), are supplied *just-in-time* during the construction period and are assembled on-site into a composite whole. This saves space and time on the construction site itself. Pouring concrete with a curing time of 28 days has no place in such a design. Adjustment options of steel elements, on the other hand, are becoming particularly important. By thinking about this and designing in detail longer than usual in this concept phase, considerable construction time could be gained on the construction site. The (practical) knowledge

that the material experts brought to the design team in the field of precast concrete and steel structures was indispensable for this. This also applies to the experience of transport experts in estimating the costs of supplying prefabricated parts. Thinking in terms of assembling elements and parts, the task of an industrial designer, is equally relevant. [Life Cycle Management, page 98]

Iconic station concept – The idea of a *toolbox* with design principles and building elements, from which the stations could be composed, including the associated construction costs, was widely appreciated. The Engineering Office was asked to further develop the overall concept into sketch designs for the modification of the seven existing stations and the two new stations to be built.

Based on the toolbox, the station access and passenger domain concept was developed as a sketch design, each with a nighttime image and a daytime image. Each presentation of the station designs started with these sketch designs, which were visualised by an intern and proved their usefulness until the final design phase. The images were chosen in such a way that they were concrete enough to serve as a promise, but at the same time vague enough that everyone could see something for themselves in them. Perhaps one could fantasise and find inspiration at the same time. The images contained the basic principle for the stations of the Hoekse Lijn with building elements that could be applied at all locations. This creates an unambiguous and individual identity across the line; a family of stations, all part of the same high-quality public transport product: the Hoekse Lijn as an integral part of the Rotterdam metro network.
Moving from vision to design is a process of precision and depth. Where the vision could still make use of philosophical reflections and poetic texts, of hypotheses and ambitions, a design requires concreteness, accuracy, and reason. The depth for this was achieved through extensive calculations, drawings, details, and models, in text, images and drawings both in 2D, 3D, and 4D. All this took place behind the scenes of the station concept since it was important for the design team and the project management that the construction started in spring 2017.

Design principles and building elements – The metro passenger does not come to the station to stay there. In essence, the traveller wants to leave as quickly as possible. For the traveller, the station is only an interruption in a longer journey, a transition place to be able to switch from ‘walking by yourself’ to ‘being driven comfortably’ and vice versa. On the other hand, local residents, including those who never use public transport, experience the station 24/7. It is part of their daily living environment and should therefore occupy a modest place in the built environment, as part of an urban ensemble. But for passengers, the station should stand out, be easy to find, be well connected to the environment and offer a safe and comfortable wait, and to finally ‘celebrate’ the arrival of the metro. Unlike a train station, where a train enters every half hour, a metro station is a facility to relax in a comfortable way for just a few minutes. Waiting at a station, even if it is only a few minutes, is generally considered a waste of time. That time should therefore be spent as comfortably as possible. Providing comfort and shelter for the waiting passenger was put at the heart of the design brief. For this purpose, large open glass shelters were designed and placed scattered along the metro platforms (Figure 3). The shelters naturally offer the traveller protection from wind and rain, but they also form colourful and clear specialisations in the facades of the public space.

The shelters are part of the multi-utility frame. All platform facilities desired by the passenger are attached to this frame. The platform lighting is also included in this frame as line lighting. The frame forms a shield between the station and the public space but also functions as a facade on that public space. Because all facilities are on the frame, the platform does not have several types of base plates, anchors, columns, etc., which is very desirable to create a clear overview, but also from management and maintenance considerations.



Figure 3. Daytime and nighttime design image of the platform and the multi-utility frame with a coloured shelter at metro station Maassluis Centrum. [Municipality of Rotterdam, Engineering Office / Hans de Boer]

The multi-utility frame is attached to the ‘floating’ platform. Inspired by the short construction time and the construction sites in the middle of inhabited areas, a standard platform plate was developed that was prefabricated in the factory. Necessary facilities such as guide strips for the blind, anti-slip facilities, facilities for cables and pipes, were included in this precast concrete slab. The platform has no corners, edges or slots that can easily become dirty.

The platform can be reached by the passenger via an entrance zone consisting of a raised forecourt and an entrance gate. This entrance zone forms the transition between the public area and access to the platform and is an important link in the ‘journey’ that the passenger takes. This is also the zone where the one-metre difference in height between ground level and platform level is overcome; the platform is at the same height as the floor of the metro carriage. This entrance zone is made of wood. The traveller hears theirs footsteps change and sees the colour and texture under their feet change.

The actual transition from public area to platform is formed by the entrance gate. This gate is situated in such a way that passengers gain an overview of the entire platform immediately, which not only benefits comprehensibility, but also shapes social safety. As beacons in space, the entrance gates are recognizable from afar as the location of the metro station. The outside is smooth and has an anti-graffiti coating. The inside of the gate is embossed and painted in a specific colour that corresponds to the colour of the shelters of the station in question (Figure 4).

Each station location requires good coordination with the surrounding public space and has its own identity. Each stop has its own colour within the spectrum, from morning yellow to evening red, from yellow on the city side of the line to sunset red on the seaside. The space around each station is planted with plants that correspond to the specific colour of the station either in terms of fruit or (autumn) leaf colour. The texture of the concrete print on the inside of the gate and the window foil on the glass of the shelters are also in each station’s specific colour.

A station is used 18 hours a day. That is why a nighttime image is just as important, perhaps even more important than a daytime image. Where during the day the gate is mainly visible because of its smooth concrete, coloured exterior, at night the entrance is mainly visible because of its coloured interior that is illuminated with warm light, as if it were a chic interior. The line lighting over the entire length of the multi-utility frame makes a line of light visible at the top and the glass shelters radiate a colourful and warm atmosphere, like a glowing shop window in public space.

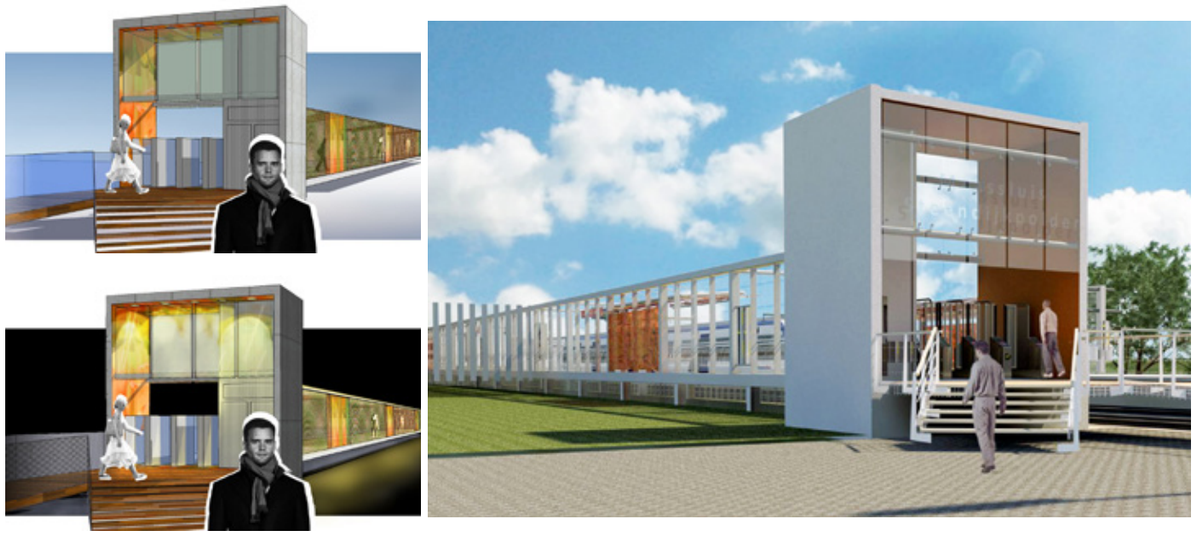


Figure 4. Daytime and nighttime image station concept and design image of metro station Steendijkpolder, Maassluis. The entrance portal with the covered gates to the platform can be accessed by stairs and a wooden slope. [Municipality of Rotterdam, Engineering Office / PD MRDH]

Metro by the sea

With the opening of the converted line on 30 September 2019, the Hoekse Lijn project was not yet finished. As the terminal station on the line, Hoek van Holland Haven is a great place to visit Hoek van Holland itself or to connect with the Stena Line ferry to England. But the beach is still about 2 kilometres away. Following the Hoekse Lijn conversion project, a track extension project followed under the name 'Metro by the sea'. The purpose of this track extension was to connect the Rotterdam metro network to the beach of Hoek van Holland. This offers the people of Rotterdam and the residents along the Hoekse Lijn the opportunity to travel comfortably and sustainably to a recreational area that is important to the region. It also offers the opportunity to develop the beach as a four-season beach. To achieve this goal, the line had to be extended by 1,200 metres from the existing Hoek van Holland Strand station, which consisted of just only a platform. And, since the beach and the sea will be there till the end of days, most of this track extension has been conducted as a single-track route. This is also based on the most optimistic passenger number estimates and associated timetables. A land tunnel was designed so the metro can pass nearby apartments and the Natura 2000 reserve 'Solleveld & Kapittelduinen'. After completion, the dune landscape was extended over this tunnel. After the metro comes out of this tunnel, it runs in an open dune landscape towards the sea with station Hoek van Holland Strand as its terminus. This is therefore a special final piece of the Hoekse Lijn. It forms a recognisable start or end point for beach visitors as a clear part of the Hoekse Lijn. Like the other stations, it is built using the familiar elements in the toolbox: glass screens, concrete gate, multi-utility frame, fish motif concrete print, and evening red as the colour of the last station from which the sunset can be observed. [Hoekse Lijn Schiedam - Hoek van Holland, page 238]

Station for a four-season beach – The station is in a unique place, on the border of beach and dunes. To the north is the protected Natura 2000 reserve, to the south the recreational dune area of Hoek van Holland. The station fits into this natural context, not by merging into it, or by 'disguising' itself as a dune, but by manifesting itself as a recognizable start or end point built from robust materials that can withstand the aggressive maritime climate. The hue of the station approximates the colour of the dune sand. The platform is surrounded on both sides by rolling dunes, so that travellers literally get off in the dunes. To meet the requirements of water legislation for sea defences, the station is slightly raised in relation to its immediate surroundings. As a result, when arriving and leaving the platform, passengers get a relaxing view of the beach and sea framed by the station hall.

The opportunity for Hoek van Holland consists of strengthening the recreational significance in the region. The history of the defence against the and the shifting coastline play a vital role in this. But it is mainly the convergence of dunes and beach on the one hand and the Nieuwe Waterweg and the Maasvlakte on the other that make Hoek van Holland unique. With the Hoekse Lijn and the beach station, it can further develop into a four-season location. It offers recreationists the opportunity to reach the beach comfortably and quickly from the Rotterdam region 365 days a year. It is therefore not only aimed at the large flow of sunbathers on a sunny beach day or for special events but is also designed for other visitors such as nature lovers, birdwatchers, beach walkers, and dog owners.

During the design phase, an integrated design was drawn up in which platforms, station building, front area, square, and surrounding dunes were placed in a relationship to each other, allowing well-considered design choices to be made. The platforms are equipped with shelters that protect against sun, wind, and rain. Offerings unobstructed views of the surrounding dunes, the shelters can accommodate up to 30 people. The size of the shelter and the position of the seats are designed in such a way that people who do not know each other automatically start talking to each other.

As a public space for the station, the front area contains essential functions such as lighting, seating, ramp, stairs, screens with route information for passengers, a pole with the characteristic yellow metro logo, which is visible from afar, etc. As an extra, the public space around the building plays a significant role as a first line of defence against wind and therefore sand and salt. The raised balcony in front of the entrance and the ramps and stairs were not only conceived based on walking lines but also to provide wind protection. This is also the case with the elongated frame with a slat fence placed on top that offers the tracks and the platform extra protection against wind. The location of the southern dune area and the one-metre-high frame right in front of the entrance of the station keep the wind out of the entrance zone. Also, designed as a robust bench, it is the perfect place for a last ice cream before the return journey. These are examples of the many interventions that are all necessary to break the wind and catch the sand.

Has the conversion achieved the ambitions?

After the opening of Hoek van Holland Strand station on 31 March 2023, it was noticeable that a striking number of travellers from the centre of Rotterdam travelled in the metro towards the sea, many with their dogs; as well as students with a crate of beer and a beach ball, and cyclists with their racing bikes. In any case, the Hoekse Lijn fulfilled the promise that the city would be located on the beach. Beach club owners could find staff more easily and, in the evening, 'city-dressed' visitors sat down at the tables among the sunburnt beach guests. Many more 'short distance walkers' came in for a coffee and apple pie. The four-season beach is starting to come true. Rolf Harbers, spokesperson for the metro operator RET, put it this way: "*The passenger numbers at Hoek van Holland Haven and Strand together exceed our expectations. We see that a relatively large number of passengers here by tapping their bank cards, which indicates that we are tapping into new target groups, such as day trippers who are not regular public transport passengers. That is good news.*" (Havenloods, 2025).

The number of daily passengers on the railway was 16,000 in 2016 while the metro line counted 24,000 passengers per working day in the first month of the start in 2019 (Treinreiziger, 2025). In the period April 2023 till March 2024 364,448 passengers travelled by metro to Hoek van Holland Strand station (Havenloods, 2025).



Figure 5. Actual realisation of metro station Steendijkpolder in Maassluis as a new stop with new apartment buildings as an example of urban development. [CC Smiley toerist]

Metro line as an impulse for urban development – The architectural vision focused not only on the stations as buildings or stops, but also as a condition for new (regional) development; the realisation of stations as a means to an end, and as the start of a process, and therefore not as the end of the project. Of course, project-based work is necessary to realise a building like a station in which planning, budgeting, phasing, construction site, logistics, etc. play a vital role. But the aim of the conversion of the Hoekse Lijn is to create a state-of-the-art mobility axis, which can serve as a carrier for the qualitative improvement of the accessibility of this part of the Rotterdam region. All this is based on the conviction that a better accessibility profile leads to a higher appreciation of the spatial quality and the business climate in this part of the region. It is clear that current visitors and residents are more satisfied with their living, working, and recreation area. But is also visible in the quantitative sense that this improved quality leads to more demand for homes and business locations. At the start of the conversion project, the municipalities on the line immediately started preparations for new residential areas and neighbourhoods around the stations (Figure 5).

The suspicion that the Hoekse Lijn has an even greater 'load capacity' then the former railway was confirmed by a study by the architects and urban developers De Zwarte Hond in collaboration with Decisio. A study, commissioned by MRDH, the province of South Holland and the municipalities along the Hoekse Lijn. Daan Zandbelt, project leader and partner of De Zwarte Hond, says:

> *"What the study shows is that each of the station areas can be further developed to its own strengths. In this way, we create diverse and varied living environments, working environments for various sectors and a rich palette of recreational opportunities, both in the landscape and culturally.* (De Zwarte Hond, 2020).

In total, the development potential for the period 2020-2040 is estimated at about 10,500 homes and 8,000 additional jobs. The development potential after 2040 is estimated at 6,000 extra homes and approximately 2,500 extra jobs. Rolf Harbers says about this:

> "*We now also see that larger housing projects are getting underway along the stations, which will further increase the number of passengers and reduce car dependence in those kinds of places. Public transport is an attractive travel option for a trip to a place near a RET metro station elsewhere in our network.*" (Havenloods, 2025).

Predictions never come true exactly, but they do bring the expectation into focus. The presence of a good metro line as a carrier of potential urban development and thus an exponent of transit-oriented development (TOD) has been quantitatively mapped out. Exploiting this potential requires a lot of effort and action from both government and market parties. Often expressed in quantitative matters, such as the number of homes or jobs, the success of the line will also have to be measured on qualitative aspects. The line creates new urban values, 'softer' aspects that are more difficult to measure, such as social cohesion, health, volunteer initiatives, satisfaction, involvement, togetherness, happiness, etc., etc. [Land Use and Transport, page 92] [Transit-Oriented Development, page 114]

Is modularity the end of architectural design? – The conversion took considerably longer than originally estimated. One reason for this was that the realisation of the complex train protection system took more time. The time for the realisation of the stations turned out to be much longer than the three months that had been anticipated. Nevertheless, the short construction time for the stations has been maintained and has proven to be part of the success of the Hoekse Lijn. It forced us to think in terms of prefabrication and assembly, so that the stations were prepared as construction kits and could be realised at the same time at several locations on the line. The stations were prepared as 'products' and realised as such. From a project perspective, it looked more like a rollout than a construction process. All elements had already been realised, inspected, approved, and prepared in transport hubs in Vlaardingen. The realisation of the stations therefore looked more like a logistical process executed with military precision than building on a large and muddy construction site. This led to lower CO_2 emissions, lower failure costs, short logistics lines, less waste of material due to measured manufacturing processes, etc. This is a welcome by-catch of remountable design and construction. [Environmental indicator, page 178]

Of course, functionality is paramount in a station design project. A station 'just has to work'. But a lot must come together in that 'normal'. Staff must be able to work properly and safely; travellers must be able to wait comfortably and safely. A station must last for a long time. Maintenance must therefore be kept to a minimum and it must be possible to carry it out in such a way that the station can continue to be in service. At the same time, a station takes a place in a community, both physically and socially. In the case of the Hoekse Lijn, the line had already been drawn into the landscape 100 years ago. The conversion of the existing stations thus joined a long-standing network of networks. The new stations are positioned in such a way that they are the beginning of the creation of new networks.

A system switch from a railway line to a metro line, from heavy rail to light rail, makes it possible to improve the public transport product: higher speed, higher frequency, more stops,

shorter stop time, etc. Qualities like these are necessary to be attractive to people who want to move around in the region. Converting a railway line to a metro line significantly increases these qualities, which significantly increases the load capacity of the line. In other words: the locations around stations will become more attractive for the establishment of shops, businesses, and homes. The lenses functionality, performance, permanence, intervention scales, and added value, as introduced in this design guide, are clearly in place.

The conversion was a complex task that could only be brought to a successful conclusion through good cooperation between all kinds of different disciplines (complexity and collaboration lenses). But it is perception and spatial quality that makes the difference. Light, colour, space, texture, details, and design were used to let the traveller experience time and place. By using an image defining the station concept to bring in visual power for both the individual stations and the entire line, an overall identity has also been created. All this was managed within the frameworks, preconditions, and administrative and financial boundaries of Dutch infrastructure projects. Furthermore, the expressiveness of the image in combination with the functionality has brought all stakeholders into one (Hoekse) line. [Integrated Infrastructure Design Lenses, page 182]

Marc Verheijen, Municipality of Rotterdam

REFERENCES ■ Bakema, J.B. (1964). *Van stoel tot stad: een verhaal over mensen en ruimte.* De Haan ■ De Havenloods. (2025, June 6th). *Metrolijn Hoek van Holland Strand bijna één jaar jong en reizigersaantallen overtreffen verwachtingen.* De Havenloods. https://www.dehavenloods.nl/nieuws/algemeen/52149/metrolijn-hoek-van-holland-strand-bijna-1-jaar-jong-en-reizig ■ De Zwarte Hond & Decisio. (2020). *Van Strand tot Stad. Ontwikkelkansen aan de Hoekse Lijn. Visie op de verschillende kernen en hun metrostations.* De Zwarte Hond ■ Kolkowski, L., & De Boer, L. (2023). *Boven verwachting? Leren van een vergelijking tussen prognoses en realisatie van reizigersaantallen bij grote stedelijke ov-projecten.* Kennisinstituut voor Mobiliteitsbeleid (KiM) ■ Kwinter, S. (1996). *Rem Koolhaas: conversation with students.* Princeton Architectural Press ■ Struijs, M. (2006). *Erasmiaans Urbanisme 1: aspecten van een Erasmiaans Urbanisme.* Hogeschool Rotterdam ■ Struijs, M., & Verheijen, M. (2007). *Ambitiedocument Hoekse Lijn.* Intern document. MRDH ■ Maandag, B. (2011). *RandstadRail Rotterdam; architectuur en constructie.* NAi uitgevers ■ Treinreiziger. (2025, June 6th). *Hoekse Lijn officieel geopend: nu meer metro's.* Treinreiziger. https://www.treinreiziger.nl/hoekse-lijn-officieel-geopend-nu-meer-metros/ ■ Verheijen, M. (2015). *Infratecture; infrastructuur als ontwerpopgave.* Nai010 uitgevers.

LESSONS

EXPRESSIVE FUNCTIONALITY BY REMOUNTABLE DESIGN AND CONSTRUCTION

The conversion project, and its conception, design and construction, provides the following lessons:

- ***A conversion from an existing railway to a metro route shortens the process of going through procedures when compared to a new route.*** Because of the embeddedness of the existing line in its surroundings, the extensive planning procedures, and environmental impact studies, which are normally required for construction, are superfluous, which leads to time savings.

- ***The addition of new stations improves public transport accessibility and offers opportunities for urban development.*** Where the line converted, the realisation of new stations offers the possibility of serving more places with high-quality public transport. This will bring more existing living, learning, working, and recreational places within reach of public transport. New stations also open up new areas that can be used for urban growth and densification through transformation or new construction.

- ***Increasing the complexity with 'soft' aspects can lead to a higher level of quality.*** Because of its complexity, it is tempting to approach a conversion project as a purely technical exercise. However, this would not do justice to the intended ambition. A higher level of quality can be achieved by increasing complexity by also including non-quantifiable aspects in planning, by organising a comprehensive approach and striving for integration in design, planning, and realisation. In the Hoekse Lijn project, steering, and communicating a recognizable image instead of technology has been one of the success factors for broad public support and a smooth completion of procedures.

- ***Use the power of an appealing and palpable image.*** An attractive image, based on functionality and restraint, was set up as a promise at the beginning of the design process and has been achieved with the acceptation and delivery of the stations. The stations serve two qualities: on the one hand, a comfortable facility for the passenger who wants to get on or off, and on the other hand, a building as a fully-fledged address with an urban facade in public space.

- ***Consider modularity and reuse as building blocks for an architectural design language.*** A characteristic of a conversion project is that passengers are often inconvenienced by the conversion works. In the case of the Hoekse Lijn, replacement bus transport was organised. To keep this temporary period as short as possible, a conversion based on prefabrication and assembly was chosen. Prompted by phasing and construction time, this method of design and construction has laid the foundation for the unique and idiosyncratic design language of the stations on the line. By adding 'detachability' as an extra dimension to prefabrication and assembly, this project has given concrete substance to the sustainable building ambition of the municipality of Rotterdam without compromising its architectural ambitions.



FEATURED DESIGN: HOEKSE LIJN SCHIEDAM - HOEK VAN HOLLAND

REGIONAL CONNECTION FOR COMMUTERS AND BEACH VISITORS

The conversion of the Hoekse Lijn from a railway into a metro line has changed its prospects from decline into revival. Will it be as succesful as the conversion of the Hofpleinlijn? Has its future already started?

Characteristics

On 31 March 2023 the first metro arrived at Hoek van Holland Strand, a seaside station where visitors can step directly onto the beach. The station was the final hurdle of the project for the conversion of a 24 km railway line into a metro line to Schiedam Centrum station. The decision for the project was taken on 13 June 2013 by the metropolitan authority for economy and public transport in Rotterdam-The Hague (MRDH) to integrate the line into the metro network of Rotterdam as a regional extension. As metro line B, which starts in the east of Rotterdam, it is the longest metro line of the Benelux. In the first year after the opening of the beach station, 364,448 visitors were welcomed by the salty sea breeze (Havenloods, 2025).

The Hoekse Lijn has a long history as railway line built back in 1893 and as international connection to the ferry service to Harwich, England. Due to the opening of the Channel Tunnel in 1994 and the growing air transport the line had lost its function as main gateway to Europe or England for international trains. The shipping company Stena Line tried to compete with its fast catamaran ferry offering a quick crossing to the UK, but was not profitable anymore. The direct train service to Amsterdam ended in 2006. From that period up until 2017 the railway line was mostly in use by local commuters. Nowadays, Stena Line still offfers a twice-daily service to Harwich.

The conversion involved the replacement of tracks and overhead wires, new level crossings, a rebuild of seven existing stations and the build of two new stations: Hoek van Holland Strand and Steendijkpolder in Maassluis. Initially, it was planned on a very tight time schedule to limit the nuisance for commuters, who had to travel temporarily by bus. For this a modular system was designed and engineered composed of remountable prefabricated elements for the stations, which comprise the entry gate, platform, shelter area and a multi-utility frame. The latter consists of a sub-system which integrates traveller information, lighting, cameras, shelter, and cables. The standardised design was informed by a station concept with spatial ambiance and user experience in mind, in order to give identity to the separate stations while viewing them as one family. Setbacks like the software for the train protection systems caused delay and postponed the metro operation several times. The first service ran on 30 September 2019 between Schiedam Nieuwland and Hoek van Holland Haven. After this, a separate project for Hoek van Holland Strand station was started. Initially this faced with objections from neighbouring residents and was restrained by a Natura 2000 area. A land tunnel for a single track was constructed and covered by dunes to overcome these. Due to its location prone to the elements several measures were taken, like sidewalls to protect travellers from the mainly south-western wind and heightened railway tracks to prevent them being covering by sand.

Significance

As gateway to Engeland and Europe, the railway line and in particular the ferry station Hoek van Holland Haven was of international importance in the past, with ferry services between London and

Previous pages: Hoek van Holland Strand, the beach station as final demarcation of the project and metroline in 2023. [Henk Leurink]



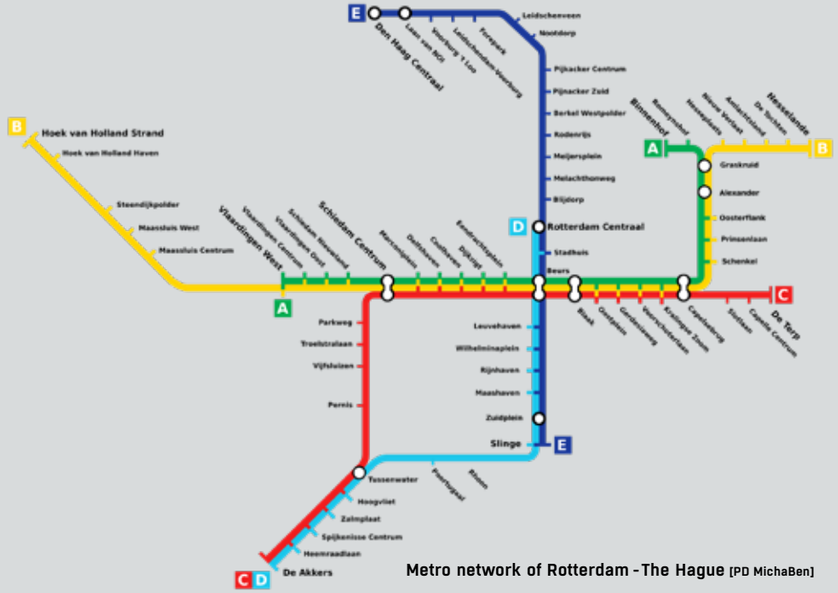
Hoek van Holland Haven station around 1907 / Poster by shipping company S.M.Z. (Stoomvaart-Maatschappij Zeeland) which maintained a daily ferry service / Arrival of a ferry of S.M.Z. at Hoek van Holland in 1950. [PD Het Utrechts Archief, Nederlandse Spoorwegen]



New metro station Maassluis Steendijkpolder. [Henk Leurink] **/ Old railway station Maassluis West in 1970.** [PD Het Utrechts Archief, Nederlandse Spoorwegen] **/ Metro station Maassluis West, opened in September 2019.** [CC Reaperexpress]







Metro network of Rotterdam - The Hague [PD MichaBen]

trains to cities like Berlin, Warsaw and Moscow. The metro line now acts as lever for urban development and offers recreation at a regional scale. The high frequency and short stops, and above all its connection to the metro network of Rotterdam, have improved the accessibility and connection of all locations along the line. The metro offers public transport for the metropolitan area for daily commuters and beach visitors, thus facilitating growth without the need for extra car traffic or extensive parking at the now four-season beach. The line has been given a new destination through a rethink of its purpose and by envisioning its future. Decline and revival offer challenges and opportunities for planners, designers, and engineers to make a difference.

Hans de Boer, TU Delft & Marc Verheijen, Municipality of Rotterdam

LOCATION: Hoek van Holland – Maassluis – Vlaardingen – Schiedam (Rotterdam) ■ **CLIENT:** Metropoolregio Rotterdam-Den Haag (MRDH) ■ **ARCHITECT:** Marc Verheijen, Municipality of Rotterdam ■ **ENGINEERING:** Engineering Office Municipality of Rotterdam, Engineering Office RET ■ **CONSTRUCTION:** VolkerRail, Mobilis B.V., Boskalis, Swietelsky Rail Benelux B.V., Maas B.V., Strukton ■ **REALISATION PERIOD:** 2017-2023.

FURTHER READING ■ De Zwarte Hond & Decisio. (2020). *Van Strand tot Stad. Ontwikkelkansen aan de Hoekse Lijn. Visie op de verschillende kernen en hun metrostations.* De Zwarte Hond ■ Maandag, B. (2010). *RandstadRail Rotterdam. Infrastructuur & constructie / Infrastructure & Construction.* NAi uitgevers.



Road crossing and a single-track tunnel through the dunes for access to Hoek van Holland Strand station. [CC Yvo Zijlstra] **/ Ruiterbrug over the Hoekse Lijn near the Maeslantkering and Oranjebonnepolder, which connects recreational routes along the Nieuwe Waterweg, designed by Happel Cornelisse Verhoeven Architecten.** [© René de Wit]



Metro station Hoek van Holland Strand bordering the Natura 2000 area Solleveld & Kapittelduinen. [Henk Leurink]



Entrance, elevated square and interior of metro station Hoek van Holland Strand. [Hans de Boer / CC IIVQ]



Reinforcement and renewal of the Afsluitdijk: Kornwerderzand sluice complex with sea lock, Lorentz sluice gates and the new Fish Migration River (under construction) as seen from the Wadden Sea. / Den Oever sluice complex with sea lock, two new pump stations, and additional sluice gates (under construction) next to the existing Stevin sluice gates, as seen from the IJsselmeer. [© Levvel, Topview Luchtfotografie]



THE AFSLUITDIJK - NORTH HOLLAND - FRIESLAND

GENERATIVE AND SUSTAINABLE REINFORCEMENT AND RENEWAL OF A HYDRAULIC ENGINEERING ICON

The Afsluitdijk is a flood barrier that for nearly a century has secured flood protection and provision of fresh water for a large part of the Netherlands. It was also the starting point for vast land reclamation mainly for food production. From a cultural perspective it embodies the Dutch legacy of hydraulic engineering and design. However, ageing infrastructure and sea level rise ask for action. Therefore, a reinforcement and renewal project was started in 2018. Could the Afsluitdijk's lifespan be extended, following new norms holding far into this century? Could its monumental appearance be maintained? Could a reinforcement and renewal approach also address and add other value than its initial value?

Regeneration is a natural process of growth, renewal and emergence of lost cells and body tissues. For infrastructure, a wonderful comparison can be made with the dunes functioning as coastal defence against floods. Flood defence likewise consists of a continuous natural process of damage and repair as well. Sometimes, nature is given a helping hand in this process through foreshore nourishment, such as in the superlative form, the 'Sand Engine' near Ter Heijde (South Holland). This involves hydraulic engineers depositing a vast quantity of sand on the seabed just in front of the beach. It causes less nuisance for the surrounding area than the traditional periodical nourishments and the work is less dependent on weather conditions. Currents and wind move the added sand naturally towards the coastal dunes.

Hard coastal defences, such as dikes, require more human intervention. Whereas people used to pay less attention to the natural environment and focus mainly on technology, today there is much more awareness of the impact of our intervention on nature. This is why the concept of 'building with nature' came into being, where nature is used as much as possible to meet the challenges of climate change and sea level rise, among others. Sometimes the concept is broadened somewhat by assuming the minimisation or even avoidance of further damage to ecological and spatial quality by paying more attention to the ecosystem and 'landscaping' in addition to technology. For the reinforcement and renewal of the Afsluitdijk, such a broadened concept was taken as a starting point, in which natural and cultural-historical values were given a clear place alongside the pursuit of innovative technical solutions. [Flood Defences, page 280]

It is important to understand the historical context well. The creation of this iconic hydraulic project was a daring feat of Dutch ingenuity at the time. The need for its construction was generally recognized after a disastrous flood in 1916. Cornelis Lely, who as Minister of Water Management presented the decision for construction to Parliament in 1918, deserves all the credit for this. As early as 1886, as an engineer, he had participated in the founding of the Zuiderzee Association and drew up the first plan for closure and reclamation in 1891; the 1892 plan also includes the phasing of land reclamation (Figure 1). His statue stands on the Afsluitdijk and Lelystad, the provincial capital of Flevopolder, is named after him (Banning, 2018). Certainly, no less undeserving was the role of Nobel laureate Hendrik Lorentz. Based on scientific research, he drew up the wave equations that were used to calculate the water levels and wave heights to determine the dike heights.

The focus was on engineering, especially because of major challenges such as tidal channels, currents, waves, the subsoil, and the confinement of the waters of the Zuiderzee, later the IJsselmeer. The Zuiderzee Works, of which the Afsluitdijk[1] is an important part – started in 1927 and in use

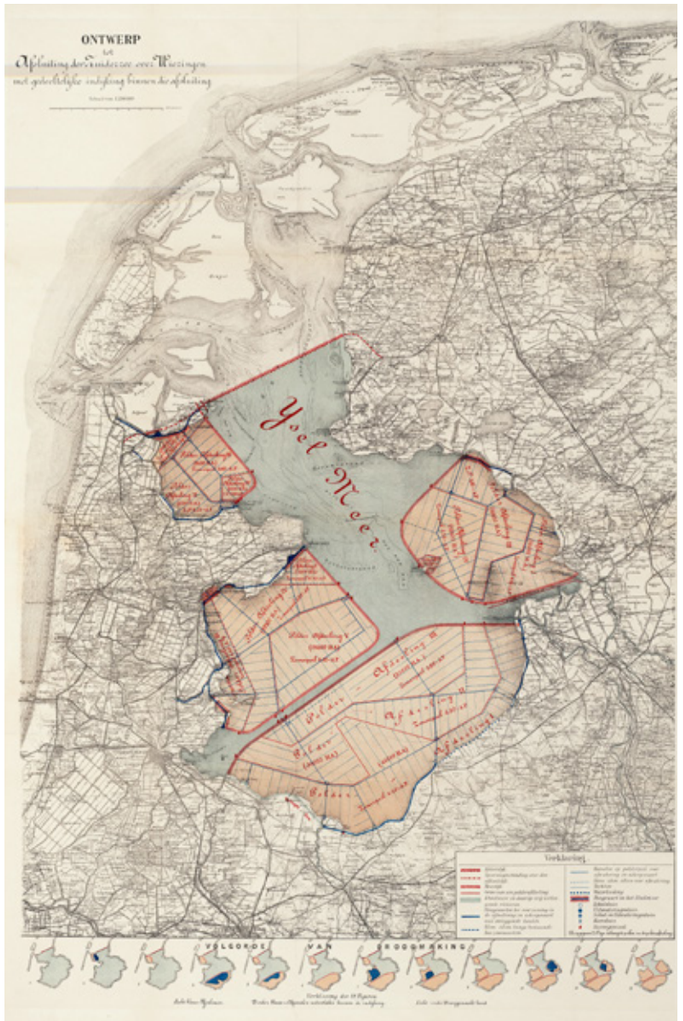






Figure 1. Design of the closure of the Zuiderzee and its phased reclamation by Cornelis Lely, 1892. [PD Zuiderzee collection] / Figure 2. The Zuiderzee around 1900 before the construction of the Afsluitdijk (top) and the Ijsselmeer area around 2019, after its construction with the Wieringermeerpolder, Noordoostpolder and Flevoland (below). [© Margot Stoete]

since 1932 – changed the map of the Netherlands forever by adding the Wieringermeerpolder, Noordoostpolder and the province of Flevoland (Vriend, 2018; Figure 2). The Afsluitdijk – 32 km long – has since protected a large part of the Netherlands. Besides protecting against high water, the Afsluitdijk is an important barrier against the salinisation of the Netherlands through the freshwater basin of the IJsselmeer (Figure 3).

The reinforcement and renewal task for the Afsluitdijk

After more than 90 years, the Afsluitdijk needed refurbishment, not only because of the ageing discharge sluice complexes at Den Oever (Stevinsluizen) and Kornwerderzand (Lorentzsluizen), but also because of rising sea levels. With the expected higher water levels and waves, not only does



Figure 3. The difference in colour between the fresh water of the IJsselmeer and the salt water of the Wadden Sea marks the location of the Afsluitdijk as seen from the Copernicus Sentinel-2 satellite. [CC ESA]

the dike need to be reinforced, but there will also be a new problem with the discharge of water from the IJsselmeer. This is because the periods in which discharging water from the IJsselmeer into the Wadden Sea is possible will become shorter due to change in the tidal movements in the future. Discharge is necessary to maintain the water level in the IJsselmeer, as it would otherwise overflow like a bathtub due to the inflow from the rivers, of which the IJssel is the most important. Figure 4 illustrates the problem created for the so-called 'discharge window' by the increase in sea level. The green line indicates the water levels at low and high tide on the Wadden Sea side and the black line the water level of the IJsselmeer. The green shaded part indicates when the level on the IJsselmeer is higher than in the Wadden Sea and thus shows the window in which discharge can take place. When the water levels in the Wadden Sea rise (red line), this window will get smaller. However, the

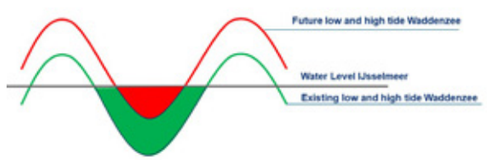


Figure 4. Reduction of the drainage window because of sea level rise. The current drainage window is shown in green and the future flushing window in red. [Hans Ramler]

amount of water that needs to be discharged does not decrease, so more will need to be discharged in a shorter time.

The need for reinforcement and renewal of the Afsluitdijk and preparation for sea level rise has led to the request from Rijkswaterstaat for a project with a net present value of 550 million euros:

1. Raising the Afsluitdijk by about 2 metres and making further reinforcements.
2. Adding pumping capacity to compensate for the reduced discharge window in the future (expected to be noticeable for the first time in 2035).
3. An aesthetic programme of requirements to define and secure spatial and visual quality.
4. An environmental plan to mitigate the environmental impact of the project by sustainability and ecological measures as part of the design and construction.

As stated before, there is now much more awareness of the impact of human intervention on the environment and nature. Rijkswaterstaat has therefore paid much attention to the cultural-historical value of the Afsluitdijk, creating an interplay between respect for the past and necessary renewal. At the same time, the principles of physics remain relevant, as reflected in the natural run-off during discharging. For more than 90 years, energy consumption for discharge has been practically negligible because it has happened during low tide on the Wadden Sea under free fall. However, this could be partly negated if pumping capacity is added.

In 2018, Rijkswaterstaat awarded the project to the construction consortium Levvel for 25 years under a so-called design, built, finance, and maintain contract (DBFM). Levvel consists of BAM, Van Oord, Rebel, and Invesis. The name refers to the water level management of the IJsselmeer and the retention of high water, two important functions of the Afsluitdijk. For the execution of the contract the consortium has set up a new special purpose company (SPC), Levvel. [Procurement of Infrastructure, page 102]

The design proposal for reinforcement and renewal

The winning and innovative design proposal by Levvel has given its own interpretation to Rijkswaterstaat's request. In addition to flood protection and water management functions, it added nature restoration, cultural history, and tourism. The project includes:

1. Raising and strengthening of the dike by BAM XblocPlus/Xbloc+ construction elements for dike reinforcement, developed in-house and renamed Levvel blocs for this project (Figures 5–6).
2. The requested discharge capacity can be fulfilled up to twice the requested volume by an expansion of the Den Oever sluice complex. Thanks to the additional discharge capacity, the use of pumps can be reduced, thus significantly reducing energy requirements. Six new pumps, which – despite their huge size – provide only part of the requested additional water discharge. The rest of the requested discharge is provided by adding additional sluice capacity, by adding 2 x 4 new sluice chambers in the Den Oever sluice complex (Figure 7).
3. Facilitating fish migration by constructing a so-called Fish Migration River between the Wadden Sea and IJsselmeer. This is an addition to the project from the consortium, aiming to contribute to an improvement of the ecosystem by re-enabling the exchange of salt and fresh water and associated marine life, which the Afsluitdijk had made impossible.
4. New guard locks at Den Oever and Kornwerderzand.
5. Road improvement of the A7 motorway along the Afsluitdijk.
6. Reinforcement and renewal of the casemates, the historic military defences at both ends of the Afsluitdijk with great cultural-historical significance and tourist importance.





Figure 5. Left: render of the reinforced dike at the Wadden Sea side with the regular pattern of the new dike revetment with the innovative Levvel bloc (Xbloc+) that allows a steep slope of the foot – placed on the old dike – while retaining the original width of the entire dike body, while the top has been raised by 2 metres. Right: render of the new cycling and walking path on the Wadden Sea side, which connect the provinces and the intermediate tourist attractions and allows the user to enjoy the view. [© Levvel]





Figure 6. Left: newly developed Levvel bloc for reinforcement of the dike at the Wadden Sea side. [© Jan Wessels] **/ Right: application of Levvel blocs for the Fish Migration River.** [© Rijkswaterstaat, Jan Wessels] **/ Figure 7. New pumps (left) at Den Oever sluice complex next to the existing sluice gates (middle). Additional sluice gates are under construction (right). This configuration is doubled within the entire complex.** [© Levvel]



The consortium started the reinforcement and renewal in 2019, which was completed in 2025 with installation of the pumping stations at the Den Oever sluice complex.

Raising and strengthening of the dike body – With the approximately two-metre raising of the dike body, its base would normally also have to be widened. This would result in damage to the protected Wadden Sea area. However, the innovative Xbloc+ made it possible to apply a steep slope to the lower slope of the raised dike body, so that the new toe of the raised Afsluitdijk does not cut off a piece of the Wadden Sea.

The open structure of the Xbloc+ is highly effective in reducing wave energy, and reducing the amount of required concrete (and therefore CO_2 emissions) by as much as 40% compared to the reference design. Initially, BAM intended to use the previously developed Xbloc to be laid in an irregular pattern. However, due to the requirement of landscape integration, this was not allowed by the landscape architects at Rijkswaterstaat. BAM then accelerated the development of the updated Xbloc+, which can be laid in a regular pattern. A total of 70,000 units – each weighing 6,500 kg – were used for the reinforcement. The result is impressive, even enhancing the spectacular simplicity, of the Afsluitdijk, which was one of the aesthetic requirements. Finally, the upper side of an Xbloc+ is roughly finished so that marine life can attach to it. The upper outer slope is composed of Quattroblocks, an existing product. Higher blocs were applied in a regular pattern to reduce the remaining wave energy and keep the surcharge within the set standard. The dike revetment – the lower and upper slopes – is designed for a lifespan of 100 years. However, the crest level is designed for the reference year 2050. If, by that time, sea level rise proves to be a reason to raise the dike further, this can easily be done by extending the dike revetment from the upper slope upwards. This will avoid wasting material.

The emergency lanes of the A7 motorway, which connect the provinces of North Holland and Friesland, no longer met the width standard. These were widened to the new shoulder width of 3.50 metres. To avoid widening the dike body towards the IJsselmeer, it was decided to reduce the width of the central road reservation. However, this meant that the standard type of guardrail could no longer be used. A new type of guardrail was therefore developed for this purpose, which also saved material.

Expansion of the sluice complex of Den Oever – The means that discharging in the Wadden Sea as part of the Den Oever sluice complex consists of the following components (Figure 7):

- two new pumping stations on either side of the sluice complex, containing two times three pumps with a total guaranteed pumping capacity of 235 m3/s,
- the existing sluice gates,
- new sluice gates with two times four concrete culverts under the A7 motorway, between the existing sluice gates.

There are two steel hoisting gates in each chute of the new sluice gates. The expected discharge from the new sluice gates will be 2,063 m^3/s at a gradient of 1 metre. The entire operation of the sluice complex operates under the adage “draining if possible, pumping when necessary”, thus making maximum use of the natural gradient. According to the models, the use of pumps will be necessary from 2035. The landscape incorporation required preserving the character of the existing hoisting towers. It was therefore decided to ingeniously install the drivers of the new steel gates below the road surface, so that they do not disturb the existing image of the complex.



Figure 8. Casemates and culvert for the fish passage through the Afsluitdijk with the Fish Migration River under construction.
[© Levvel, Topview Luchtfotografie]

The Fish Migration River – One of the highlights of the reinforcement and renewal of the Afsluitdijk is the Fish Migration River near the Kornwerderzand sluice complex (Figure 8). The construction of the Afsluitdijk in 1932 had a huge impact on nature. Together with the disappearance of the natural transition from fresh to salt water, an important fish migration route was abruptly cut off. A Fish Migration River with a culvert crossing the dike partly restores this encroachment on nature. A culvert is an opening through which a predetermined amount of water can flow.

Fish generally have a poor ability to withstand a sudden transition from salt to fresh water and vice versa. It is therefore not sufficient to merely construct a culvert in the dike body. Therefore, a meandering river on the IJsselmeer side has been provided. This river contains a salt tongue that moves back and forth with the tides, allowing the fish in the river to swim gradually from salt to increasingly fresh water. Fresh water from the IJsselmeer is discharged into the Wadden Sea via the Lorentz discharge sluices. This discharge occurs at low tide, when the water in the Wadden Sea is lower than in the IJsselmeer. The fresh bait flow ‘lures’ the fish into the sluice basin. The entrance to the Fish Migration River connects to this sluice basin. Just as the hydraulic engineering world followed the construction of the Afsluitdijk closely, now the ecological world is watching to see how this piece of engineering will turn out.

Reinforcement and renewal of the casemates – Both on the North Holland and Friesland sides, so-called casemates were built during the construction of the Afsluitdijk (Figure 8). The casemates on both sides of the Afsluitdijk have been restored to their original state as much as possible because of their great cultural-historical value. The Kazematten Museum at Kornwerderzand, at the Friesland side, provides information on the Battle of the Afsluitdijk during the German attack on the Netherlands in May 1940. Together with access to the Fish Migration River and the Afsluitdijk Wadden Centre, this is expected to become a major tourist attraction.



Figure 9. Aerial view on the Den Oever sluice complex and the Afsluitdijk in the direction of Friesland. [© Levvel, Topview Luchtfotografie]

To what extent can an integrated approach to a reinforcement and renewal task generate added value?
The fact that the reinforcement and renewal proposal for the Afsluitdijk went a step further than was requested for flood protection and water management, raises the question to what extent the proposal is characterised by an integrated approach to the original task. This task is set in the context of the transitional system challenges due to climate change, energy transition, circularity, and biodiversity. To answer this, many lenses have been used that are introduced in this design guide. [Integrated Infrastructure Design Lenses, page 182]

When looking at *functionality,* the purpose and usefulness of the reinforcement and renewal is beyond doubt. The Afsluitdijk will safeguard the Netherlands from flooding far into this century. In addition, the capability to discharge surplus water from the IJsselmeer into the Wadden Sea will also hold far into this century, still using the free fall principle as long as possible to limit the use of energy. The quality of the water in the IJsselmeer, a freshwater basin for a large part of the Netherlands, is improved by reducing saltwater leakage through the upgraded discharge sluices (Figure 9). The barrier to fish migration is mitigated by the innovative Fish Migration River which contributes to a more natural environment for sea life and greater biodiversity. Another functional aspect is the widening of the emergency lanes of the A7 motorway. This contributes to more safety in case of car trouble. With the strengthening of the dike at the Wadden Sea side, the bicycle route was reconstructed, which offers cyclists and hikers an astonishing view and experience. The cycle route also offers the opportunity of tourist visits to the Fish Migration River, the Kazematten Museum, the Wadden Centre, and the Afsluitdijk monument. Altogether, this can boost the tourist sector. [Integrated Infrastructure Design Method, page 290]

The use of a DBFM contract by Rijkswaterstaat is a guarantee for the so-called RAMS requirements which are related to the *performance* of the Afsluitdijk. Not fulfilling the requirements for the reliability, availability, maintainability and safety will lead to a penalty imposed by the owner and client Rijkswaterstaat to the company Levvel, that executes the contract. As such, this type of contract requires long-term *collaboration* between the client and the consortium, and within the consortium. The significance of the Afsluitdijk and the relevance and scope of the reinforcement and renewal project require a collaborative goal. The different parties and their interests must be aligned to be successful in the realisation, but also in the operation due to the nature of the contract. Apart from political, financial, organisational, and judicial aspects, the design of the project and its broad functional scope have also led to a high degree of *complexity*. Unexpected issues – which led to delays and design changes – challenged the project, the budget, and the management of this already complex project. However, in the end there are few projects with such broad support among the public, politicians, and stakeholders. [Stakeholder Analysis, page 112]

With existing infrastructure like the Afsluitdijk, we can speak about a ‘tabula scripta’. The Rijkswaterstaat architects, as client’s representatives, were very aware of the dilemma of the necessity of the reinforcement and renewal at this *intervention scale* and the possible negative impact on the iconic appearance of the Afsluitdijk, as regional connection and national landmark. Its longtime presence embodies its *permanence* – as infrastructure can endure for centuries and being an irrefutably part of the landscape and history. Rijkswaterstaat architects were very keen to avoid fancy adjustments, applying the adage spectacular simplicity.

The *perception* of the Afsluitdijk by car drivers, cyclists or hikers differs strongly. Driving a car makes people feel humble due to the length of the Afsluitdijk and the size of the IJsselmeer. Cyclists and hikers can enjoy the astonishing scenery of the Wadden Sea in a calming trip. The requirement of Rijkswaterstaat to make the design for the dike revetment resilient is a textbook case for *adaptivity* and *resiliency*. The new crest level of the dike is based on the prediction of the seawater level in the reference year 2050. By requiring a design lifetime of 100 years for the revetment, this can easily be extended to a higher dike crest level. With this projected long lifespan,

measures for reducing the ecological footprint should be also part in the pursuit of *sustainability*. The use of Xbloc+ for the revetment of the dike at the Wadden Sea side had a significant impact on the reduction of CO_2 emissions as open concrete structures, especially given the enormous number of used blocks. Limiting the pumping capacity by the introduction of additional discharge sluices saves energy, which adds up during its lifespan. The Fish Migration River as well contributes to a more sustainable natural environment for generations. Regarding integrated design and its assumed potential to *add value* – in comparison to a strict functional approach – the reinforcement and renewal project gives enough clues to conclude that it delivered more than its minimum of securing flood protection and water management. When considering *spatial quality* as addressed by the project, its *user value* is clear, as well as together with its *future value,* as the extended functionality and future preparedness show, being based on sustainable principles and measures improving ecology and environment. Its *user experience* is improved by applying visual quality requirements captured by the notion of spectacular simplicity. This is expressed in the Xbloc+ pattern and in the cycle route which connect the tourist attractions, so users can experience the elements and scenery of the Wadden Sea. [Benefit-Oriented Design, page 276]

The reinforcement and renewal project secures the initial social and economic value of flood protection and water management for a large part of the Netherlands far into this century. The transport connection for the northern provinces is up to its current norms, maintaining its present and future economic value. The new *added value* lies mainly in the improvement of the ecological system and contribution to biodiversity by the Fish Migration River. From a cultural perspective, the project has built on the existing cultural assets, maintaining its iconic appearance for the future. The names of the new Stevin and Lorentz water discharge sluices honour the legacy of Dutch hydraulic engineering and design.

Hans Ramler, TU Delft

NOTES

1. Why is the closure of the Zuiderzee called Afsluitdijk and not Afsluitdam? A dike protects land from water, while a dam is located between two bodies of water. The name was probably chosen because of the many earlier plans of the Zuiderzee Association, which envisaged not only closing off the sea but also reclaiming the part behind the Afsluitdijk.

REFERENCES ■ **Banning, C., & Voigt, E. (2018).** ***Cornelis Lely. Ingenieur van het Nieuwe Nederland.*** **Pharos Uitgeverij** ■ **Vriend, E. (2022).** ***Eens ging de zee hier tekeer.*** **Atlas Contact** ■ **Wikipedia contributors. (2025, May 16th).** ***Afsluitdijk.*** **https://nl.wikipedia.org/wiki/Afsluitdijk** ■ **Wikipedia contributors. (2025, April 25th).** ***Zuiderzee.*** **https://nl.wikipedia.org/wiki/Zuiderzee** ■ **Wikipedia contributors. (2025, June 3rd).** ***Cornelis Lely.*** **Wikipedia. https://nl.wikipedia.org/wiki/Cornelis_Lely** ■ **Wikipedia contributors. (2025, April 10th).** ***Slag om de Afsluitdijk.*** **Wikipedia. https://nl.wikipedia.org/wiki/Slag_om_de_Afsluitdijk.**

LESSONS

GENERATIVE AND SUSTAINABLE REINFORCEMENT AND RENEWAL OF A HYDRAULIC ENGINEERING ICON

Large and complex projects always provide new lessons from which to learn. The main lessons are:

- ***Introduce two-phase contracts for large and complex projects.*** From a contractual perspective, a single-stage DBFM contract is vulnerable for unexpected events. It is better to introduce two-phase contracts in case of these kinds of projects, to reduce risks and to try to avoid unexpected events. In that case, a DBFM contract can be attractive only for the second stage of the project when the risk profile is better defined and manageable. Rijkswaterstaat is already introducing another approach.

- ***Innovations require expertise and trust from both the client and contractor.*** In many cases, investors and owners are risk-averse towards innovations, as shown by the first reaction when the new innovative Xbloc+ (Levvel bloc) was proposed for more than 30 km at the most severe spot of the revetment on the Afsluitdijk. Only due to close collaboration and courage from the engineers of the owner (Rijkswaterstaat), the contractor Levvel and the consultants on both sides, this solution was implemented. Of course, it had been thoroughly tested in the Deltagoot test facility of Deltares. The lesson learned is that it is possible to introduce high-impact innovations with the right skills and trust among the owner, contractor, and consultants.

- ***Mutual respect between client and contractor forms the basis for success.*** The architectural ideas did not match the initial approach of the contractor. Listening to each other's motivation and the willingness to reach out to each other led to the desired spectacular simplicity of the renewed Afsluitdijk. The contractor is proud of the result, while the architects at some points had to compromise without impacting the overall idea. With mutual respect, great results can be achieved.

- ***Take advantage of new insights to recover from the negative impact of past interventions.*** It is never too late to repair natural damage from the past, which was the case with fish migration from the sea towards the Dutch rivers. In the 1930s, less attention was given to natural preservation. Furthermore, there is nowadays more knowledge about making cuts in an existing dike. With the right motivation, skills, and finance it is possible to restore fish migration in places where it was not considered possible. This example can be an important motivation to introduce this idea in other places around the world.



Pedestrians in Korte Koediefstraat looking at the old and new architecture in the centre of The Hague, 2021. [© The Hague & Partners/HPM]

THE HAGUE CITY CENTRE

PEDESTRIANISING PUBLIC SPACE

Pedestrianisation – the design strategy of restricting or removing vehicle traffic to prioritise pedestrians – requires long-term commitment integrating multiple perspectives, transdisciplinary work, and intersectoral approaches. Pedestrianisation directly engages with pressing questions about the future of inner cities. How can historically car-oriented urban cores be redesigned to prioritise pedestrian-oriented public space without compromising accessibility and economic vitality? What shifts in the design practice are required to translate such long-term ambitions into spatial reality?

European cities have long been at the forefront of pedestrianisation, with early initiatives emerging in the 1940s. Cities such as Stockholm and Rotterdam were among the first to plan for car-free zones in their central commercial districts, followed soon after by Cologne, Copenhagen, and other capitals. By the 1970s, pedestrianisation had evolved into a comprehensive urban strategy, integrating traffic management, economic revitalisation, environmental improvement, and social benefits. Success depended on a broad-based approach involving community engagement, spatial planning, supportive legislation, and financial frameworks. During this period, such these strategies played a pivotal role in addressing the decline of inner-city areas, where falling residential populations and the rise of car-oriented suburban retail and housing developments had accelerated urban decay. The pedestrianisation efforts laid the groundwork for rethinking and redesigning public space, while establishing the means to implement and manage pedestrian-friendly environments effectively.

The redevelopment of The Hague's city centre offers a concrete response to questions surrounding the reconfiguration of car-oriented urban cores in favour of pedestrian-oriented and liveable public spaces. With the Nota De Kern Gezond (Memorandum A Healthy Core) as a starting point in June 1988, the plans for redeveloping the public space in The Hague inner city were set in motion. The municipal executive of The Hague stated that "in addition to new buildings and renovation of other buildings, there must be a drastic improvement in the residential function, the cultural climate, the structure of the core retail sector, the redesign of public spaces […] and an increase in traffic liveability. Wherever possible, this process should be realised in partnership with private investors." Improvements in public space and its redesign, especially focused on pedestrians and slow-moving traffic, would go hand in hand with changes to the urban programme. Accordingly, this exemplar stands out as a formative example that helped lay the groundwork for integrated infrastructure design in dense urban settings. During the initial phase of the pedestrianisation of The Hague city, public space was seen as the territory of society, defined strictly as the space that is not privately owned. This definition was later broadened. Building on the Fourth Spatial Planning Memorandum, a key national policy document on spatial planning published in the same year, public space came to be defined as any connective tissue between human activities – places of encounter, vital for the liveability and identity of our everyday environment. Specifically, regarding The Hague city centre, the pedestrianisation strategy expanded on the municipal memorandum Hart door Den Haag. Mixed use proved to be a quality boost, with public spaces facilitating communication between various places. An illustrative case is provided by The Hague, whose municipal policies and long-term vision aim toward a fully pedestrianised city centre by 2050 (Figure 1).

Pedestrianisation: A long-term commitment

The approach taken by the municipality of The Hague laid the foundation for redesigning the public outdoor environment through a detailed integrated analysis of mobility networks, examining

both local activities and urban connectivity. It also included a study of the street-level experience, with particular attention to the visibility and accessibility of public facilities and amenities for diverse social groups in the adjacent buildings. On this base, it evaluated the configuration of pedestrian path systems to reveal the potential of spaces to support pedestrian flows, connectivity, and functional integration, thereby informing design decisions that enhance urban performance and liveability. This pioneering inner-city design strategy introduced a coordinated approach to planning and integrating multiple urban systems – such as transport, water, and public space – to maximise pedestrian use and comfort. Innovatively, it promoted joined-up planning for urban redevelopment, enabling more efficient use of space in high-density areas, and contributing to improved performance, sustainability, and quality of life. Having been implemented for almost four decades at the present, the relevance of this design strategy is proving to be greater than ever, as urban density increases and the vision of a becomes more central to planning ambitions. The recent municipal general mobility and environmental strategies, respectively Netwerkstrategie 2040 and Omgevingsvisie Den Haag 2050 (both 2025), imply that all residents should, in principle, have convenient access to daily services within a fifteen-minute walk or cycle ride. While these plans agree on extending the pedestrian areas in the city centre, the pedestrianisation strategy will also be applied to support the creation of liveable, vibrant, and safe neighbourhoods and resilient, healthy communities outside of the inner city. [X-Minute City Concept, page 202]

Organisational framework – A wide array of services and specialists have taken on responsibilities for various aspects – traffic, public transport, lighting, paving, planting, street furniture, and more – reflecting an integrated infrastructure design strategy. Therefore, an advisory committee on public space design was established to support the implementation of Nota De Kern Gezond, namely the Adviescommissie Openbare Ruimte (Advisory Committee Public Space, ACOR). Within this framework, the municipal departments of urban development (DSO), public affairs (DPZ), and city management (DSB) have always had their own distinct responsibilities. The advisory committee reviews design proposals for the public space based on an integrated framework document and public space manual, both adopted by the council, and advises the municipal executive. The committee also promotes policy development and sustainable innovation in the design of public space. ACOR is an interdepartmental committee composed of staff from DSO, DPZ, and DSB, supplemented by an external designer from the advisory committee on spatial quality. As such, all relevant disciplines involved in the design, implementation, and management of public space are represented. Since 1994, an additional broad alliance, comprising builders, developers, financiers, transport providers, and the municipality of The Hague, was founded. Umbrellaed under the name Den Haag Nieuw Centrum, this group, involving over fifty participants, included representatives of developers, builders, investors, office-building trusts, housing corporations, residents, estate agents, the national Real Estate Agency, and senior municipal officials. The coordination ensures further alignment in adding and mixing urban programmes and redesigning public space. For each detailed development area, a project manager is designated to coordinate road reconstruction and maintenance, newly-build urban projects, repairs and installation of underground infrastructure, transport works, and public space activities. [Project Management for Integrated Infrastructure Design, page 106]

Addressing social and economic value – When published in 1988, the initial plan aimed to deliver a significant "impetus to the appearance, liveability, and economic standing of The Hague city centre", generating value both socially and economically. In addition to the anticipated cost savings, investment in the public realm is seen as a quality enhancement with the potential for long-term returns. The ongoing large-scale efforts to make The Hague's city centre more pedestrian-friendly can be embedded in social cost-benefit analyses (SCBA). These enable transparent, evidence-based

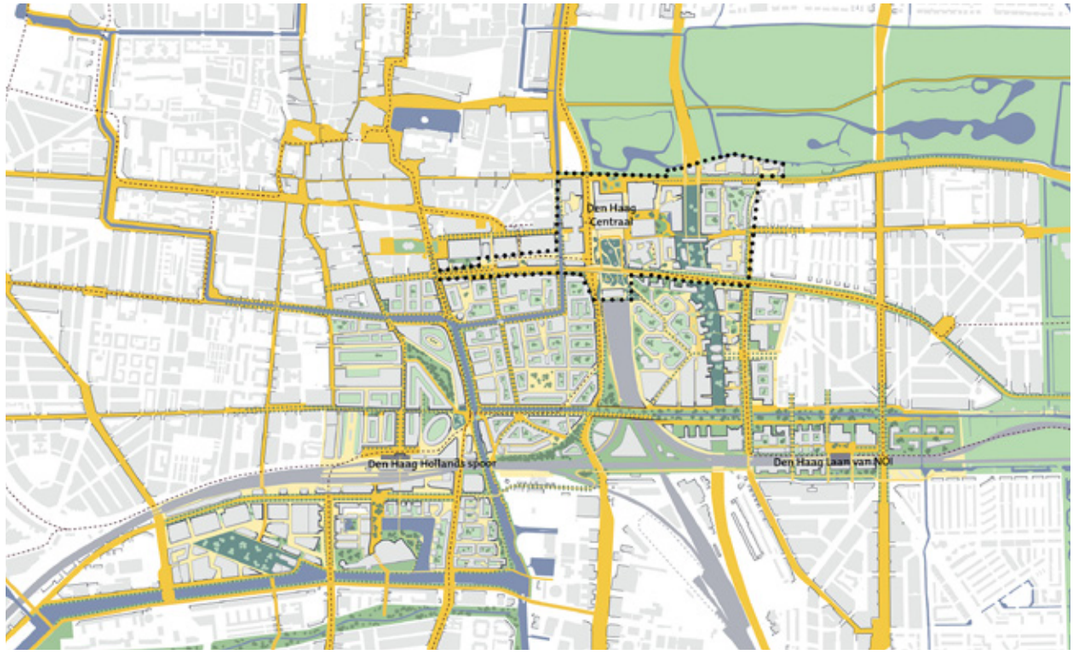


Figure 1. Pedestrianisation vision for The Hague's new centre: the Central Innovation District positioned between and around the railway stations. [© Municipality of The Hague]

investment decisions that prioritise long-term societal value, such as well-being, health, liveability, and safety, while generating significant economic value and strengthening the local economy. For social value, it is essential that public space functions as a common: a collective good that is non-rival and non-excludable. In The Hague, infrastructure investments have inevitably influenced land value through positive external effects. The quality of public space design, from pavement type and facade detailing to colour schemes, ground floor use, and car-free streets, have directly impacted not only the value of the project itself, but also that of surrounding properties. With the focus on pedestrianisation the negative external effects of car dominance like congestion, emissions and accidents were addressed. Investing in urban infrastructure, therefore, generates both social and economic value.

The trade-off between traffic and the quality of public space has come down to setting priorities as intended. The focus has shifted to pedestrians, creating friendlier spaces and a changed traffic circulation system: car traffic is reduced, and public transport is promoted in the city centre. Bus services are rerouted around the centre rather than through it. Car access to the centre is ensured through dedicated parking areas and nearby short-stay car parks, and a flexible vehicular traffic system is in service, distinguishing between day and night flows for safety reasons. In implementing this pedestrian-focused approach, identifying and engaging stakeholder groups through a power-interest matrix enhances the effectivity of such a design strategy. Stakeholders with high power and high interest, such as city planners, local government, and business owners, play a crucial role in shaping priorities and traffic policies. Meanwhile, managing the interests of groups with lower power but significant interest, like daily commuters and divers residents, is essential to ensure broad support and minimise resistance to changes like rerouted bus services and restricted car access. [Social Cost-Benefit Analysis, page 200] [Land Use and Transport, page 92] [Benefit-Oriented Design, page 276] [Stakeholder Analysis, page 112]

Modernistic driven infrastructure development – The urban structure of The Hague underwent a significant shift in the 20th century, moving from a pedestrian- and tram-oriented centre in the past century to a layout increasingly dominated by car traffic, a transition that occurred before pedestrianisation became both necessary and inevitable. The turning point came a century ago with major cut-throughs through the historic city centre to facilitate traffic flow, as envisioned by Hendrik Petrus Berlage in the Extension Plan for The Hague from 1908, altered in the subsequent decades. These infrastructural interventions, like Grote Marktstraat and Hofweg, were gradually implemented from the 1930s to the 1950s, under growing pressure from motorised traffic (Figure 2). Torenstraat was another cut-through along which the Netherlands' first multi-storey car park was built. National developments reinforced this trend. The first Rijkswegenplan (Highway Plan, 1927) envisioned a network of high-capacity roads for motorised traffic only. This included Rijksweg 13 (now A13) and Rijksweg 4 (A44) as existing roads, widened to four lanes in roughly the same period, and Rijksweg 12 (A12) – a dedicated and grade-separated motorway from The Hague to Utrecht – with the Voorburg-Zoetermeer section opened in 1936–37 as the Netherlands' first true motorway. These car-oriented developments at the edge of the city influenced local policy as documented in Memorandum Regarding Roads in the Western Part of South Holland of 1933. Within the city, raised infrastructure was implemented. The Schenkviaduct (1940) was the most prominent, spanning railway lines to connect the centre with the southeast. Later, on the edge of the inner city, the Prins Bernhardviaduct and the sunken urban motorway Utrechtsebaan were added (opened respectively in 1975 and 1976). They connected to the A12 via high-speed links. This car-oriented strategy brough with it the creation of large car parks in the inner city, while replacing older structures or underused land. Traffic jams became a daily occurrence in the inner city. In the 1970s and 1980s, congestion exposed the limits of car-based mobility. At a time when traffic in the city centre was declining, particularly during rush hour, while off-peak cycling increased, a new integrated infrastructure design approach was introduced.



Figure 2. Crowded traffic in Papestraat, one of the narrow inner-city streets in The Hague, 1955. [PD Haags Gemeentearchief]

Pedestrianisation: Densification and hybridisation of the city centre and revisited networks

The modal shift, following the implementation of the pedestrianisation strategy, represents a clear trend change. In four decades, the number of car movements in the inner city has dropped significantly. The pedestrianisation of much of the city centre has led to road narrowing and reorganisation of traffic circulation, and, for example, the decommissioning of a car viaduct, which has since been partially demolished. Meanwhile, pedestrian accessibility has actually improved. Also, with this modal shift, the resident population in the area has increased markedly. The momentum for this change was driven by a renewed pull towards the city and accompanied by a revival of high-density urban living. Over the same four decades, the number of residents in The Hague city centre grew by 71.44%, with the largest increase occurring in the first ten years after the implementation of the pedestrianisation strategy, and in the most recent years. Although several massive mono-functional office buildings from the 1980s have been subject to redesign and

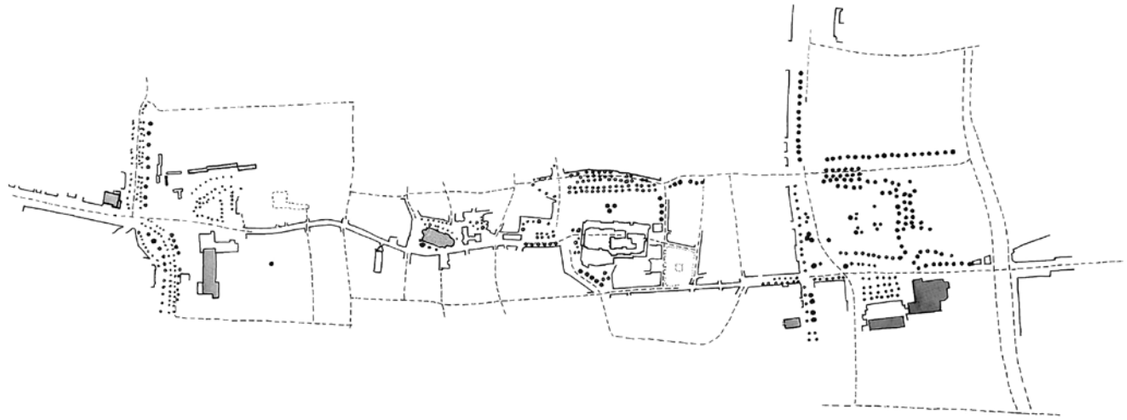


Figure 3. Spatial analysis of one of the city's lines: Westeinde–Centrum–Poten–Centraal Station (1980). [© Municipality of The Hague]

reuse, the results are now becoming visible, also in a qualitative sense. Further densification has also led to additional facilities as well as hybridisation of programmes. There is now a wealth of cultural and leisure amenities, co-working spaces, and meeting points, which shape public life, in addition to the commercial function of the area. They enrich public space by encouraging social interaction, creativity, and a sense of community. Public spaces have been designed inside and outside. They activate the urban environment, making it more inclusive, lively, and attractive for a diverse range of users throughout the day. In addition, Leiden University and TU Delft have also established a presence here, apart from The Hague University of Applied Sciences. These public institutes bring not only knowledge, innovation, and a steady influx of young talent to the city but also foster vibrant academic and cultural places.

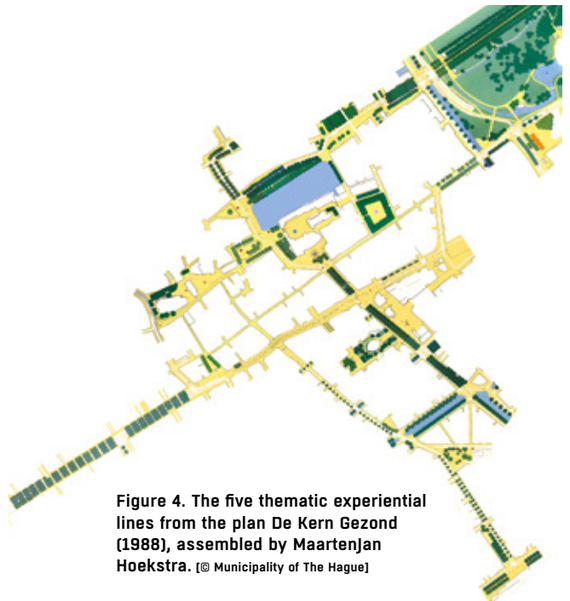


Figure 4. The five thematic experiential lines from the plan De Kern Gezond (1988), assembled by MaartenJan Hoekstra. [© Municipality of The Hague]

Reprioritisation of transport flows and transformation of public space – This ongoing integrated design approach to the traffic challenges in the inner city, particularly manifested in cross streets rather than in main roads, is based on a historical-morphological spatial analysis, published as early as in the 1980 municipal memorandum The Structure of the City Centre (Figure 3). Whereas Nota De Kern Gezond was the first to adopt its conclusions for revising and integrate design strategies, new strategies continue to work on the city's characteristic spatial structure, with dominant lines following the underlying ancient dune ridges in an east-west direction (Figure 4). The morphological study of The Hague's inner city is supported by extensive documentation of pedestrian routes through drawings and photographs. This has provided a layered understanding of the spatial structure and layout of the city centre, which reflects the user's perspective and experience of a fragmented urban environment

which finds its origin in top-down planning and compartmentalised approaches, reinforced by institutional boundaries and discipline-driven methods.

Today, within the pedestrian-friendly zone, a coherent design of the walking network reinforces a distinct spatial character that actively engage with their surroundings. Historic routes, open spaces, and a fine grid of streets continue to define the inner-city experience. The results of the morphological analysis are evident: it grounded a proposal to transform the major east-west axis in the inner-city public space network, and a first crosslink in the north-south direction. One axis is predominantly green; another consists of a series of enclosed urban courtyards; there is a shopping promenade; a row of urban streets; and in Spuikwartier an urban corridor now stretching all the way to Den Haag Centraal station. A cross-axis – the Berlage cut-through – was transformed in a main road, allowing car passage. This all characterised by the following locations and streets:

1 The public spaces formed by Lange Vijverberg, Toernooiveld, Korte Voorhout, Malieveld, and Koekamp have long served as essential green lungs within The Hague's urban fabric. Many of these date back centuries and have retained their open, wooded character, offering a vital counterbalance to the density of the built environment.

2 Behind Plaats, a fine-grained network of intimate streets emerges – some of the oldest in the city, such as Papestraat – highlighting the enduring qualities of medieval urban patterns.

3 A central axis formed by Buitenhof, Dagelijkse Groenmarkt, and Kerkplein links three historically enclosed squares. Once used primarily as court, market, and religious spaces, these squares are mostly framed by monumental architecture, illustrating the layered history of civic life in The Hague.

4 Streets like Vlamingstraat, Spuistraat, Lange Poten, and Korte Poten form a chain of narrow shopping streets that were pedestrianised in earlier decades. These routes are among the oldest commercial arteries in the city, still retaining their human scale and bustling atmosphere.

5 In contrast, Prinsegracht, Grote Marktstraat, and Kalvermarkt were part of a major modern intervention. Designed as main traffic routes created by cut-throughs of existing buildings, they introduced a structural spine for urban infill and densification and became the setting for The Hague's first generation of high-rise developments in the city centre.

Revaluation of the waterway and green networks – Following the layer approach, slow-changing water management in the dune landscape is crucial for sustaining the natural water balance in the city. In the inner city, particularly the Hofvijver and Lange Vijverberg (dating back to the 13th century), the partly filled Spui watercourse (which has drained excess water from the Hofvijver since 14th century), and the lower canal ring around The Hague (mainly built in the 14th/15th century) respond to rainwater fluctuations. These distinctive historic water structures continue to organise water flows, while shaping public spaces. Porous materials such as the scenic, tree-lined gravel promenade along Hofvijver and Lange Vijverberg support natural infiltration, while harder surfaces remain necessary in high-traffic areas with significant surface water management needs. Given the subsoil conditions and numerous underground cables and pipes, combined with the goal of planting city trees with large root structures capable of receiving rainfall, brick paving was the clear preference in the design of the public space. This choice also aims to enhance visual attractiveness.

The pedestrianisation strategy has also aimed to enhance the inner city's green character and image by preserving its monumental plantings, and connecting green enclaves, while fostering collaboration across various levels of governance (Forestry Commission, province, municipality). Concrete interventions include linking the pedestrianised zones to the broader urban green structure, such as the primeval forest Haagse Bos located just outside the inner city near the central station,

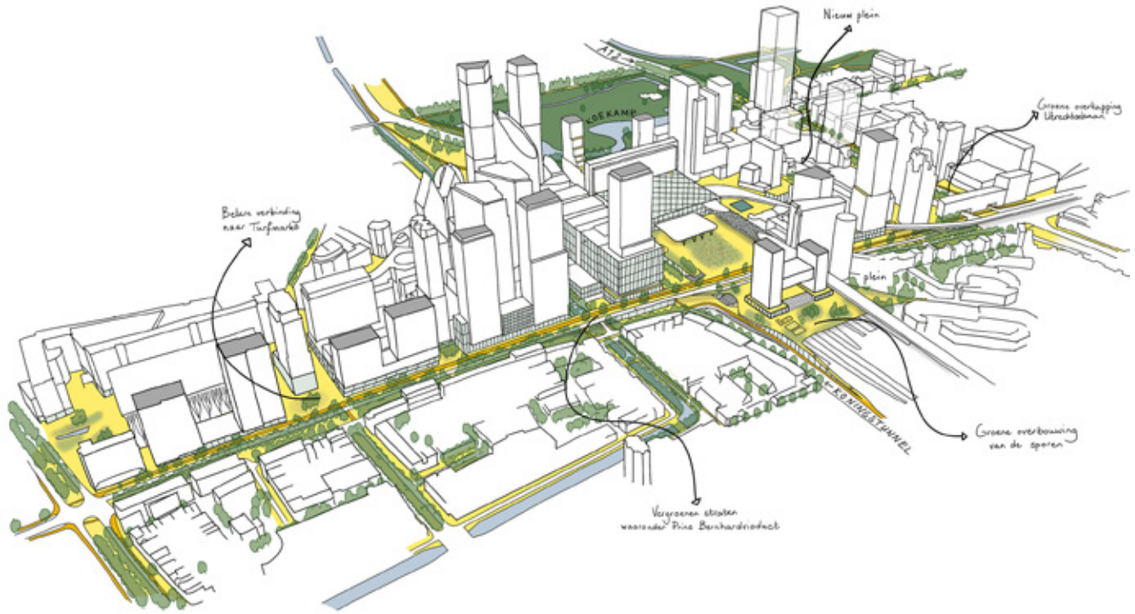


Figure 5. Sketch impression of the future surroundings of Den Haag Centraal station (2024). [© Municipality of The Hague]

integrating the 15th-century avenue plantings along the Hofvijver, and enhancing typical street-lined trees in various 19th-century public spaces, thereby reinforcing both historical continuity and ecological connectivity. Additionally, the strategy seeks to reinstate the balance between trees and greenery and underground and above-ground infrastructures, ensuring a harmonious integration of nature and natural systems within the urban environment. [Layer Approach, page 94] [Nature-Inclusive Infrastructure, page 296]

Incorporating the railway stations in the urban transport and public space network – The pedestrianisation strategy and general redesign of the public space to improve the quality of the inner city of The Hague has now been expanded to a much larger area. To accommodate ongoing inner-city growth while preventing the growth of car use, a mobility transition towards clean and space-efficient transport modes has become essential, aiming for a modal split of 40% walking, 25% cycling, 20% public transport, and 15% car use. This shift is supported by applying the inverse mobility pyramid – prioritising the most sustainable modes first (walking, cycling, public transport, then cars). This is made feasible through transit-oriented development (TOD), strong integration with the cycling network, and the design of high-quality public spaces with greenery, active ground floors, and inviting places to stay. The extended inner city is being by three train stations in close proximity: Den Haag Centraal, Den Haag Hollands Spoor (HS), en Den Haag Laan van NOI (Nieuw Oost-Indië). Their distance from each other ranges between just 1 km to 1.7 km apart. Together with the metro, tram, and regional and local bus services, these three high-quality public transport hubs give access to an area of at least ten square km. The current extension of the strategy focus to the areas around these 'new' centralities makes it feasible to further transform and urbanise the inner city, enabling people to live, work, and travel without relying on a car (Figure 5). In addition to the historic inner-city area where the initial plans were implemented, pedestrianisation has been extended to the three neighbouring areas: the Den Haag Centraal station area; the Laan van NOI station and Beatrixkwartier area; and the Hollands Spoor station and Laakhaven area. The various urban renewal projects in



Figure 6. Top and bottom left: Grote Marktstraat, with Nieuwe Haagse Passage, Papestraat and Molenstraat in 2025. [© Maurice Harteveld] / **Figure 7. The Netkous, part of one of the RandstadRail connections.** [CC A4-Nieuws]

these areas are accompanied by upgrades to public space and amenities. More so, pedestrianisation investments around the three stations accompany a major urban development in the heart of The Hague: the Central Innovation District (CID), situated between them. Envisioned as the city's new economic and urban core, it integrates living, working, learning, innovation, amenities, and pedestrian-friendly public space (Figure 6). Again, the municipality ensures coherence through an integrated area strategy developed in collaboration with partners. [Transit-Oriented Development, page 114]

Infrastructural key projects – The extensively implemented pedestrian-friendly integrated infrastructure design strategy includes several key projects which could be identified as specific types of integrated infrastructure design themselves. The key projects can be categorised in three ways: *infrastructural objects*, involving large-scale new or revised infrastructures; *infrastructural spaces*, where existing infrastructures are not necessarily altered but their potential is enhanced; and *infrastructural acupuncture*, consisting of small, often overlooked additions that play a critical role in the functioning of the overall network. In The Hague, this tripartite framework is exemplified through a range of interconnected interventions.

Infrastructural objects include major undertakings such as the Souterrain Tramtunnel and the Koningstunnel, which restructure urban mobility at a foundational level by relocating respectively tramlines and car traffic underground. Whereas the Koningstunnel is diverting vehicles underground in order to reduce congestion in utilitarian ways in favour of street level flows, the tram tunnel underneath Grote Marktstraat adds underground qualities for the pedestrian. The latter also provides a car park access on one level in the main commercial zone, and tram stops on another

level with direct access to one of the adjacent department stores. This not only streamlines transit flows, with growing numbers of traffic movements in place, but also frees up surface space significantly while benefitting the surrounding properties in social-economic valuable ways. As both infrastructure and architecture, the Souterrain Tramtunnel reflects a hybrid ambition; more than just a traffic solution, it is a multi-layered, spatially rich environment where user experience is shaped through daylight, glass separations, and seamless transitions that connect it to the urban fabric. Another example is The Netkous light-rail viaduct near Den Haag Centraal station. As an elevated, mesh-like tram connection that combines a striking architectural form with separation of transit and street-level activity, it further embodies this category in the form of 'infratecture', The Netkous exemplifies how thoughtfully-designed infrastructure can go beyond functionality to create urban identity and spatial experience (Figure 7). Its expressive, mesh-like form not only facilitates efficient transit but also contributes to the spatial quality of the area, integrating architectural and structural aspects into a coherent whole, in which the balance between form, material efficiency, and force distribution becomes visible. The result is a piece of infrastructure that is not only technically effective, but also socially, culturally, and visually meaningful. This enhances conditions for pedestrian movement and enables the creation of more accessible, walkable public space. [Infratecture, page 284]

Infrastructural spaces, meanwhile, are represented by the transformation of Turfmarkt into a high-quality pedestrian corridor and the strategic revisions for the areas near Den Haag Centraal, Laan van NOI, and Hollands Spoor stations. Turfmarkt exemplifies an inner-city infrastructural space where existing urban infrastructure is not radically altered but its potential is unlocked. Originally a wide, open green interstitial space, with parallel parking in the 1980s, it has been transformed into a smaller, and lively pedestrian spine, enabling ongoing urban densification and today's high-rise development. Apart from improved pedestrian connectivity and accessibility within the city centre, which fosters social interaction, pedestrianisation of this infrastructural space is now supporting offices, businesses, cultural institutions, university buildings, and homes, while reinforcing The Hague's focus on sustainable, people-centred urban design. The area around Den Haag Centraal station, as an example of a design strategy for infrastructure-entangled inner-city spaces, is enhancing the potential of existing transport and urban systems without radically altering their physical form. Back in the 1980s the station area, including Anna van Buerenstraat, functioned as a broad thoroughfare dominated by vehicular traffic and surfacelevel parking, before its transformation into a more vibrant, compact pedestrian corridor that supports the city's urban densification ambition. [Design Strategies for Infrastructure-Entangled Spaces, page 300]

Finally, infrastructural acupuncture is seen in smaller, precise interventions like the design of the pedestrian Nieuwe Haagse Passage, an arcade extending a 19th-century arcade towards Grote Marktstraat. The new and old interior public spaces provide shortcuts through formally closed urban blocks between major pedestrian arteries. As such, the intervention results in a finer pedestrian network. Furthermore, the linear atrium of the City Hall provides a finer grid by offering a parallel interior public space along Turfmarkt during daytime. Another example is the passageway through Den Haag Centraal station and the public interior of the New Babylon shopping and office complex, which extend the pedestrian path system. Another form of urban acupuncture may be found in the discreet yet vital water retention infrastructure at the Hofweg tram stops. Each of these smaller elements plays a subtle but essential role in stitching the urban fabric together, while addressing the climatological conditions under which pedestrianisation is implemented in a culturally situated manner. [Urban Pathway Design, page 312]

Pedestrianisation: How robust and adaptive is its strategy in the future?

Amid constantly changing urban conditions, the implementation and development of the design strategy for pedestrianisation remains challenging, because it requires bringing together people

of diverse backgrounds, lifestyles, and incomes. This has already led to more variation in public space design and a diversification of strategic interventions to promote social connection, encounters, and learning. Moreover, all city districts are strongly oriented towards the city centre. Hence, rethinking the inner city will pose growing challenges in a future that prioritises public services for compact, integrated, and community-focused neighbourhoods.

As remote work becomes increasingly common, many people are spending more time at home, leading to a stronger connection of inner-city residents to their immediate surroundings. As a result, urban residents are increasingly appropriating or even co-creating public spaces, transforming them into extensions of their homes. This process of 'domestication' underscores the need for urban designs that cater to diverse, locally-focused needs, promoting accessible and inclusive public spaces that support community life.

Additionally, there is a shift towards less institutionalised office buildings, altering the traditional perception of inner cities as central business districts (CBDs). This shift is further accompanied by a growing emphasis on local mobility and the use of nearby public spaces, such as (pocket) parks and recreational areas, with a particular focus on active modes of transport, which supports a broader pedestrianisation strategy.

Lastly, the pedestrianisation strategy must address environmental sustainability by incorporating circularity, using durable, eco-friendly materials, and reducing climate change impacts through urban heat mitigation, water management, and enhanced biodiversity. By integrating these agendas, the pedestrianisation of The Hague's inner city can contribute to both a more liveable and sustainable future urban environment.

As The Hague's city centre continues to evolve under the banner of enhanced appearance, liveability, and economic strength – the initial targets of the pedestrianisation strategy – several crucial questions emerge. In an increasingly hyper-diverse society, how can infrastructure design for public space ensure that the city's visual identity remains affectively resonant across multiple social and cultural groups? As lifestyles shift and fragment over time, what forms of adaptive infrastructure will be required to sustain and redefine urban liveability? And finally, as economic growth as well as transition drive the centre's transformation, to what extent can infrastructure design help preserve the city's openness, thus ensuring that central infrastructures remain up to date as well as accessible, inclusive, and genuinely public for all? [Life Cycle Management, page 98]

Maurice Harteveld, TU Delft

REFERENCES ■ Afdeling Algemeen Verkeersonderzoek. (1982). *Jaarcijfers Verkeerstellingen 1982, Deel II, Kordon Binnenstad 's-Gravenhage.* Gemeentelijke Dienst voor de Stadsontwikkeling 's-Gravenhage/Hoofdafdeling Verkeer, Afdeling Algemeen Verkeersonderzoek ■ Afdeling Verkeer, Vervoer, Openbare Werken. (1988). *Nota De Kern Gezond, Plan voor de Herinrichting van de Openbare Ruimte in de Haagse Binnenstad.* Gemeente 's-Gravenhage ■ Departement Omgeving. (2018). *Planning Beleidsplan Ruimte Vlaanderen. Strategische visie.* Departement Omgeving, Afdeling Beleidsontwikkeling en juridische Ondersteuning ■ Dienst Stedelijke Ontwikkeling. (2022). *Mobiliteit in Den Haag, 2018-2021.* Gemeente Den Haag: DSO / Strategie, Externe Betrekkingen, Portfoliomanagement en Onderzoek ■ Dienst Stedelijke Ontwikkeling. (2024). *Ontwikkelvisie Den Haag Centraal: Vernieuwen, Verbinden, Verassen. Central Innovation District (CID).* Gemeente Den Haag ■ Dienst voor de Stadsontwikkeling. (1980). *De structuur van de binnenstad. Een stedebouwkundige benadering van de dwarswegproblematiek.* Gemeente 's-Gravenhage ■ DHIC/Gemeente Den Haag/Dienst Publieke Zaken. (n.d.). *Aantallen inwoners per 1:1, eenheid personen, perioden: 1985 – 2025, gebiedsniveau buurten: 12 Voorhout, 13 Uilebomen, 11 Kortenbos, 14 Zuidwal.* Den Haag in Cijfers ■ Dienst voor de Wederopbouw en de Stadsontwikkeling. (1957). *Den Haag, snel groeiende stad.* Dienst voor de Wederopbouw en de Stadsontwikkeling ■ Gemeente Den Haag. (2025). *Netwerkstrategie 2040. Voor een leefbaar en bereikbaar Den Haag.* Gemeente Den Haag ■ Gemeente Den Haag. (2025). *Concept Omgevingsvisie Den Haag 2050. Thuis in een groene metropool aan zee.* Gemeente Den Haag ■ Gemeentelijke dienst van Stadsontwikkeling en Volkshuisvesting. (1933). *Nota Betreffende Verkeerswegen in het Westelijke Deel van Zuid-Holland.* Gemeentelijke Dienst van Stadsontwikkeling en Volkshuisvesting ■ Meyer, H., Josseling de Jong, F., Hoekstra, M.J., & Harteveld, M., et al. (2006). *Ontwerp voor de Openbare Ruimte.* Uitgeverij SUN ■ Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2021). City Deal Ruimte voor Lopen. In *Staatskrant*, 4664, 2 februari 2021. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties.

LESSONS

PEDESTRIANISING PUBLIC SPACE

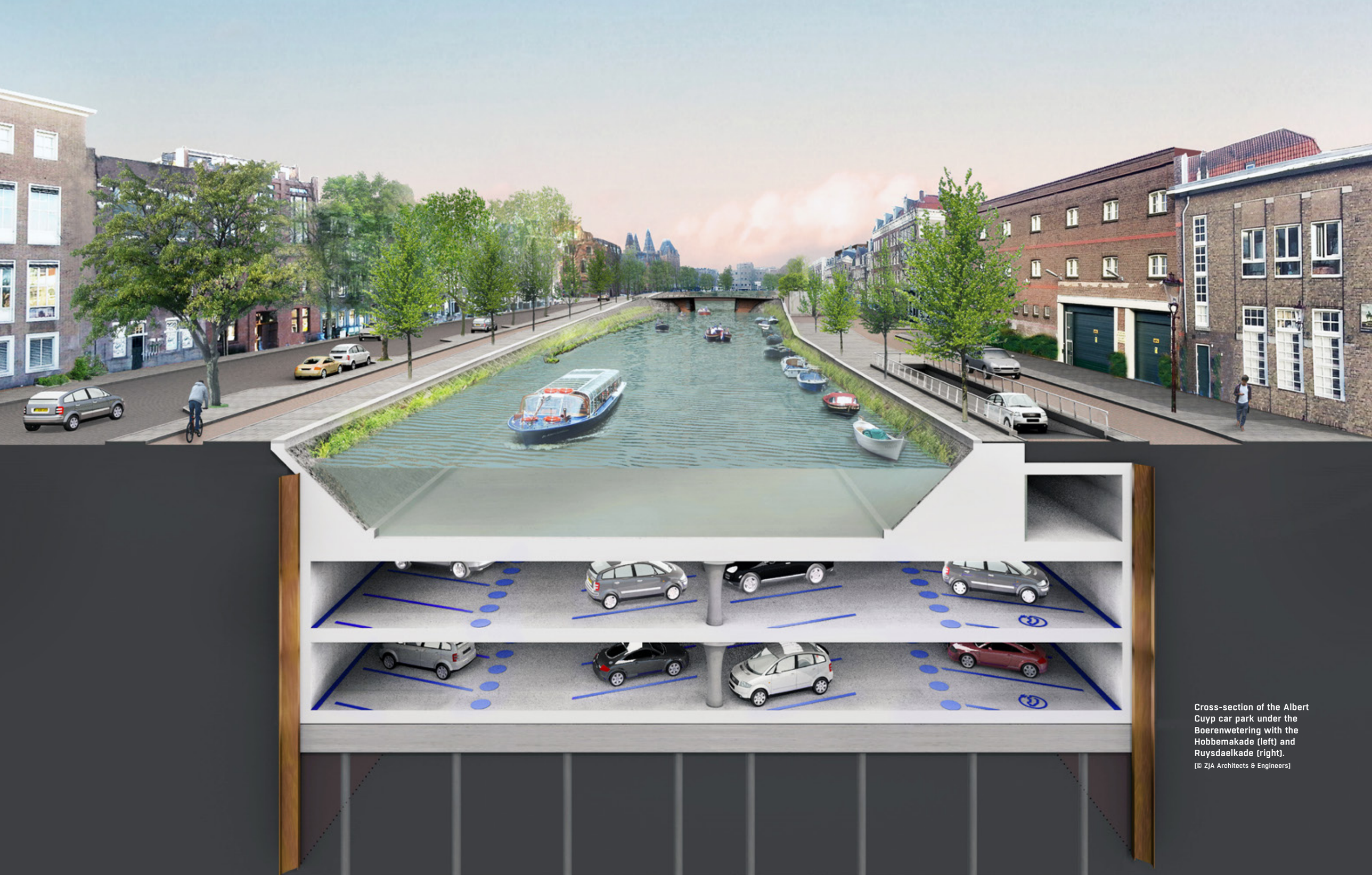
– ***Prioritise pedestrian networks as a framework*** By giving the highest priority to pedestrian networks in the city core, a strong development framework is established. These networks have remained intact for decades, while the surrounding built environment and public space continue to evolve. A well-defined framework allows for future adaptation to socio-economic changes, ensuring that pedestrian routes remain relevant and effective long-term, while also accommodating shifts in urban life as well as societal change, with changes in behaviour patterns, perceptions, and thus preferences.

– ***Pedestrianisation as a long-term commitment supported by an organisational framework*** Pedestrianisation is not the responsibility of a single entity. A wide range of specialists, including urban designers, traffic planners, transport providers, developers, architects, property owners, housing experts, economists, and ecologists, all play key roles. This requires an integrated design strategy that fosters collaboration across sectors. An advisory committee focused on the design of public space and public space networks is essential to ensure a balanced and holistic approach to urban development, reflecting both the social-spatial and cultural aspects of the city.

– ***Align pedestrianisation with environmental sustainability goals*** The pedestrianisation of public spaces also stimulates other active modes of transport as well as public transport hubs to create interconnected urban areas, which support sustainable living and reduce the city's carbon footprint. In addition to its focus on enhancing the inner city's green character and image, the pedestrianisation strategy also aligns with broader contemporary greening goals aimed at fostering environmental sustainability. These include promoting sustainable greening, enhancing biodiversity, stimulating native plant species, and revitalising and cleaning urban water. By integrating green strategies and sustainable water management, pedestrianisation can contribute to climate resilience more effectively. Pedestrianisation supports resilient, sustainable infrastructure that promotes economic development and human well-being, ensuring accessible, and green public spaces, while future strategies must guarantee equitable access to inclusive, affordable urban areas and enable orderly, safe, and responsible movement for all residents.

– ***Define key projects based on integrated infrastructure design*** Defining specific integrated infrastructure design projects helps to manage urban development at various scales. These projects align short-term actions with long-term urban and socio-economic changes. By bringing together different sectors at the project scale, these initiatives facilitate effective collaboration and create tangible, short-term improvements. Such projects also help anticipate future needs and steer the development process in a cohesive direction, ensuring urban evolution stays on track.

– ***Redoing the past through pedestrianisation*** The drastic modernistic transformation of the city into a car-oriented, less liveable, and environmentally unfriendly environment can be redone by today's generations through pedestrianisation. What previous generations did in terms of prioritising cars and traffic can now be reversed with the right focus on public space, walkability, and green infrastructure. The challenge lies in reclaiming urban space for people, turning it into a healthy, vibrant, and sustainable space for future generations.



Cross-section of the Albert Cuyp car park under the Boerenwetering with the Hobbemakade (left) and Ruysdaelkade (right).
[© ZJA Architects & Engineers]

FEATURED DESIGN: ALBERT CUYP CAR PARK AMSTERDAM

RETAKING PUBLIC SPACE

With the construction of neighbourhoods in late 19th and early 20th century, people had no idea how transport would develop in the future. Certainly, they could not imagine that the public space would also be used for the storage of means of transport, namely the car. In order to regain spatial quality, we must look for space that may not be obvious, without banning cars completely.

Characteristics

The Albert Cuyp car park is located under the Boerenwetering, a canal on the border between Museumkwartier and De Pijp. Both districts are part of the Amsterdam-Zuid area and are located directly south of the historic canal belt. The Museumkwartier was developed in the late 19th and early 20th centuries, and includes the Rijksmuseum and large mansions based on a spacious street plan. Nowadays, it contains a concentration of cultural hotspots like the Van Gogh Museum, the Stedelijk Museum, and the Concertgebouw. The northern part of De Pijp (Oude Pijp neighbourhood) was developed in the same period; the street pattern dates to the same extension plan of 1872. However, the housing was set out in narrow and deep four-storey workers' houses of moderate quality in long and narrow streets. As part of 'Plan Zuid' from 1917 by architect H.P. Berlage, the development of the southern part of De Pijp (Nieuwe Pijp neighbourhood) resulted in better homes, a more varied street pattern and a spacious streetscape with architecture by the Amsterdam School movement. Nowadays, especially Oude Pijp is a lively neighbourhood with, among other attractions, the daily Albert Cuyp market, bars, and shops in the Ferdinand Bolstraat. The Boeringwetering is considerably older and already visible on a map from 1560. It was originally dug for the drainage for the reclamation of the peat area near Amstelveen and for agricultural and market gardening land use, and became an important waterway for transport of products to the city.

With the increase in car ownership since the 1960s and, 70s, the car has taken up a lot of the already scarce public space within the narrow streets – especially in the highly densified Oude Pijp neighbourhood (15,000 inhabitants, 4,160 businesses, and 10,742 addresses per km² in 2024) (Allecijfers, 2025). The district council of Amsterdam-Zuid decided to build a car park under the Boerenwetering with a capacity of 600 cars – 90% of which are for residents – and 60 bicycles. The car park consists of two layers with a separate entrance and exit on the Ruysdaelkade, and a local access road along the canal. It is located between two bridges: the Brandweerbrug at the 1e Jacob van Campenstraat and the Diamantbrug at the Albert Cuypstraat. The construction is 260 metres long and 30 metres wide and is built based on the wall-roof method. First, a construction pit was made by driving sheet piling on the quay sides and between the quays, from which 72 million litres of water were pumped, after that, the soil was excavated. An underwater concrete floor was poured on site, reinforced by hybrid steel fibre and supported with tension and compressive anchor piles. This was needed for stability because of the load from the structure, the parked cars and the water mass, and because of the upward pressure of the groundwater. The concrete retaining walls for the permanent sheet piling, the wide slab floors and the columns were produced as building modules in the builder's factory and placed on site. The contract covered the design, construction and 15 years of maintenance worth 35 million euros.

Significance

The Albert Cuyp car park is the first parking under a waterway in Amsterdam. Given the lack of space – as well, in the underground due to pipes, cables, the metro tunnel, and foundations of houses – and the need for good accessibility, the location is not so strange. Spoorzone Delft also has an underground parking with a reconstructed canal on the roof, which previously been filled in.



The Albert Cuyp car park (dot) is located at the border of the districts Museumkwartier (west) and De Pijp (east), together called Oud-Zuid. [PD Centraal Bureau voor de Statistiek] / **Expansion plan of 1872 south of the historic Amsterdam canal belt with the Boerenwetering. To the east the Rijksmuseum on Stadhouderskade and to the west the polder for development of De Pijp.** [PD A.J. van der Stok]



Boerenwetering with the Rijksmuseum (left) and newly built houses in De Pijp (right) in 1891. [PD Stadsarchief Amsterdam] / **Boerenwetering and Ruysdaelkade near Korrelbrug at Eerste Jan Steenstraat with the Rijksmuseum in the background, ca. 1905** [PD Stadsarchief Amsterdam] / **Parking at Ruysdaelkade in 1971.** [PD Stadsarchief Amsterdam, J.M. Arsath Ro'is]



The car park has a high utility value due to a maximum use of space, because the roof is supported by a single row of round columns in the middle. There is a clear and spacious floor plan with parking spaces at a 70-degree angle so that the user can park easily and comfortably. Together with the good lighting and long sightlines, this contributes to both physical and social safety for the user. The open character with few structural obstacles could offer opportunities in the future for other functions when car ownership decreases in the long term.

In addition to making things easier for residents by removing the need to search for a free parking space each time, more space has also been made available for residents and neighbourhood activities. Because the parking is mainly intended for residents, part of the parking spaces on the street (273 in total) have disappeared, so that the public space and the streetscape have been taken over by pedestrians and cyclists again. This is especially visible at Ruysdaelkade, which now has a completely different amenity value. The entrance and exit for cars with the two ramps take up limited space on the quay. The two pedestrian entrances, made of glass, are also restrained within the streetscape. Hobbemakade, a main road located opposite, was also included in the redevelopment of Ruysdaelkade, and received new paving and tree planting. With the redesigned quays, Boerenwetering now forms a coherent whole of public space serving the residents of both districts, which have also been under a protected cityscape since 2022.

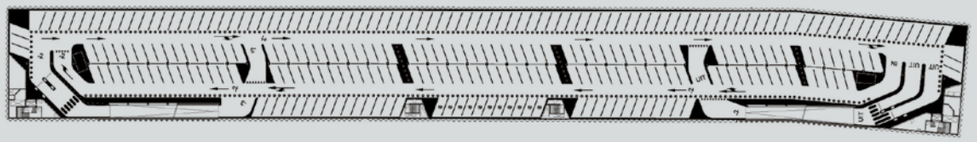
The car park received several architectural and engineering awards: ESPA Gold Award 2018, Dutch Concrete Award 2019, jury prize Architizer A+Awards 2019, and the Award of Excellence for Architectural Achievement 2019 from the International Parking & Mobility Institute. It was nominated for the WAN Transport Award 2019.

Hans de Boer, TU Delft

LOCATION: Amsterdam ■ **CLIENT:** Area council Amsterdam-Zuid, Municipality of Amsterdam ■ **DESIGN:** ZJA Architects & Engineers ■ **ENGINEERING:** ZJA Architects & Engineers, Van Rossum, CRUX ■ **CONSTRUCTION:** Max Bögl Nederland B.V., Volker Staal en Funderingen, ABT, Beens Groep, De Vries & van de Wiel, Proton Bau, DCN, Van Velzen, Van Dorp Installaties, Van Haastere B.V. ■ **REALISATION PERIOD:** 2016-2018.

FURTHER READING ■ Allecijfers. (2025, October 20th). *Statistieken wijk Oude Pijp.* Allecijfers. https://allecijfers.nl/wijk/oude-pijp-amsterdam/ ■ Feddes, F. (2025). The city as movement space. On the walking city, the car city, and the bicycle City. In *A millennium of Amsterdam. Spatial history of a marvellous city.* THOTH Publishers, 256-277 ■ Gemeente Amsterdam. (2019). *Het gesprek met de stad. Over de Agenda Amsterdam Autoluw.* Gemeente Amsterdam ■ Van Tilburg, S., Wagner, C., & Arkesteijn, R. (2021). Grensverleggende parkeergarage. Albert Cuypgarage gebouwd onder bestaande watergang met geïntegreerde keldervloer. Cement, Kennisplatform over betonconstructies.





Cross-section and plan view of the first parking layer of the Albert Cuyp car park. [© ZJA Architects & Engineers]





Construction pit. [© Max Bögl] **/ Building equipment on the roof and construction of the car entrance at Ruysdaelkade.** [© ZJA Architects & Engineers]



Car exit at Ruysdaelkade. / Pedestrian entrance at Ruysdaelkade. / Interior space of the parking. [© ZJA Architects & Engineers]





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Benefit-Oriented Design

Engineers build the foundation of human welfare and well-being by designing basic amenities for the long run, such as drinking water systems, farming systems, transport infrastructure, housing, sewage, and flood protection. But how to ensure that these designs produce maximum benefits to society? And how to prevent unintended negative impacts? This can be done by applying seven sustainable design principles.

PURPOSE – The challenge is to create designs that have the largest possible positive long-term impact on the welfare and well-being of people. That sounds simple, but for engineers and designers it is an art to design projects in such a way that they do not cause unintended negative impacts that cast a shadow over the intended positive ones, like a dam that destroys a downstream ecosystem. The trouble of unintended side effects is that we often do not see them in advance.

If engineers and designers succeed in only designing *net positive* i.e. sustainable project alternatives, it becomes difficult for public decision makers to choose an unsustainable solution. When it comes to increasing human welfare and well-being, engineers and designers are the ones making the designs and are therefore holding the key. By means of *benefit-oriented design*, they can make a large contribution to the sustainable development goals of the United Nations.

APPROACH – Designing is making choices while looking forward. During the design process, engineers and designers identify measures to solve a problem, leading to increased welfare and well-being. This is a creative, though well-structured process, consisting of the following steps:

1. *Problem analysis:* what is the problem or chance? What stands in the way of our welfare and well-being? Which goals do we wish to achieve with a project?
2. *System analysis*: what is causing the problem or what creates a chance? Which driving forces lie underneath these causes or opportunities?
3. *Function analysis*: which functions must the design fulfil to solve the problem or grab the chance?
4. *Study of alternatives*: in how many different ways can the functions be fulfilled? Which physical objects are needed for this? What are the dimensions of these objects? Which additional measures are needed?
5. *Impact assessment*: what are the positive impacts on welfare and well-being of each alternative? Are there any unintended negative impacts to be expected? And what are the costs of the alternatives?

The *golden rule* during the design process: base your choices on expected final welfare and well-being impacts (Figure 1). To identify measures that generate these positive impacts, there are *seven sustainable design principles*. Each principle takes another angle. Each principle adds a new aspect to the other six principles. Which principles are relevant for you depends on the topic on which you are working.

A broad set of alternative designs is the key to more impact for society. An engineer or designer who has only designed two different highway improvements will never find out that a railroad or a waterway or any other option is even more attractive in terms of welfare and well-be-

APPLICATION
The approach can be applied to every system and object that engineers and designers design, preferably in the early stages of a design process.

LIMITATIONS
In the late stages many design choices, such as building volumes, locations or technologies, have already been decided upon, leaving limited room for applying the seven sustainable design principles to their full potential.

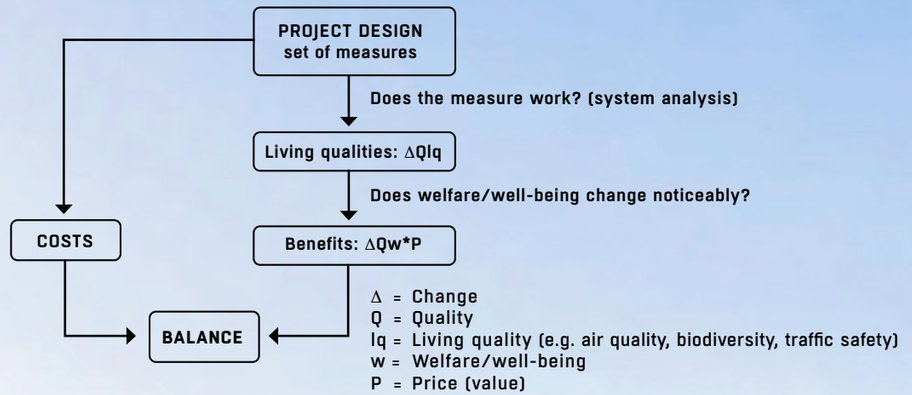


Figure 1. Benefits result from improving living qualities: do not only look at the increase of living qualities by your project but focus on the increase of benefits instead. This is the key to create a design with a positive balance in terms of welfare and well-being / Mechelse Heide nature reserve, Flanders: 274 m long wooden structure for an elevated bicycle connection as part of a recreative bicycle route, designed in collaboration with Maat-ontwerpers. [© Witteveen+Bos]



ing. The alternative you forgot to design cannot be selected, even though it may be the winner in terms of net impact (Table 1). The seven sustainable design principles in a nutshell:

1 *Work with instead of against nature.* Make use of natural processes when your project interferes with or could interact with them. This can make your design cheaper and can prevent unintended negative side effects. It may also lead to extra ecosystem benefits.

2 *Minimise and optimise the use of resources* by: (a) limiting demand and unnecessary use, (b) using renewable instead of non-renewable resources, (c) using resources efficiently. This reduces the total life cycle costs and CO_2 emissions of your design.

3 *Close production chains by using waste as a resource.* This makes your design cheaper because fewer new materials are being produced and transported. It can also generate extra revenues when waste can be sold as a resource.

4 *Add multiple functions to your design in an optimal way.* The key is to surprise your commissioner with an extra function and additional benefits, by a relatively small alteration to your design.

5 *Create a design that can easily be adapted to new future circumstances*, such as new climatic circumstances or new future preferences and needs of people. This reduces life cycle costs and creates additional future benefits.

6 *Design 'together with' instead 'for' stakeholders.* Allow people who are positively and negatively affected by your project an active role in your design process. Their local area knowledge and refreshing ideas improve your design. This leads to more positive and less negative impacts and possibly also to a smoother execution of your project.

7 *Combine physical and societal measures in your design.* Physical measures often merely create a potential benefit. This potential can be captured by adding societal measures that change people's behaviour or their socio-economic circumstances. E.g., an extra wide beach only leads to recreational benefits by adding a licensing system for beach vendors.

	Alternative A	Alternative B	Alternative C	Alternative X
Intended positive welfare impacts*	+ 100 + 50 0	+ 60 + 50 + 50	+ 100 + 50 + 50	+ 100 + 50 + 50 + 30
Unintended negative welfare impacts*	- 30	- 10	0	0
Costs: - investments - maintenance	 - 40 - 50	 - 60 - 50	 - 60 - 40	 - 30 - 30
Net impact	+ 30	+ 40	+ 100	+ 170

Table 1. Three alternatives based on the the seven sustainable design principles; all of these offer a positive sustainability balance, so a decision maker can always choose a sustainable design. However, the alternative (X) one may have forgotten to design might have the highest impact. *Contribution to the United Nations Sustainable Development Goals.

Rob Nieuwkamer †, Witteveen+Bos & Elisabeth Ruijgrok, Witteveen+Bos

FURTHER READING ■ Ruijgrok, E.C.M., & Nieuwkamer, R.J.L. (2013). De duurzaamheidsparadox. *De Ingenieur*, nr. 4, 52-53 ■ Keeney, R.L. (1996). *Value focused thinking. A path to creative decision making.* Harvard University Press ■ Bouw, M., & Van Eekelen, E. (2020). *Building with Nature. Creating, implementing and upscaling Nature-Based Solutions.* Ecoshape, Nai010 publishers ■ Ruijgrok, E.C.M. (2011). *MKBA-kengetallen voor omgevingskwaliteiten: aanvulling en actualisering.* Witteveen + Bos, Steunpunt Economische Evaluatie, Rijkswaterstaat ■ Ruijgrok, E.C.M., Smale, A.J., Zijlstra, R., Abma, R., Berkers, R.F.A., Nemeth, A.A., Asselman, N., De Kluiver, P.P., De Groot, R.S., Kirchholtes, U., Todd, P.G., Buter, E., Hellegers, P.J.G.J., & Rosenberg, F. A. (2007). *Kentallen waardering Natuur, Water, Bodem en Landschap. Hulpmiddel bij MKBA's.* Witteveen+Bos, Ministerie van Landbouw, Visserij en Natuur.



Deventer, Overijssel: new secondary canal in the floodplains of the IJssel River for extra discharge capacity combined with a marina. / North Holland: 3D printed concrete bicycle bridge for the reconstructed N243 road Alkmaar – Avenhorn. [© Witteveen+Bos]



Flood Defences

Many regions across the globe are low-lying and prone to flooding. Historically, floods have caused devastating impacts and catastrophic consequences, and these effects are being further exacerbated by climate change and urbanisation. Over the centuries, mankind has been actively seeking robust solutions to prevent flooding.

PURPOSE – Flood defences are critical hydraulic structural systems and engineered measures designed to prevent or mitigate the adverse effects of flooding. Flood defences therefore are of immense importance to protect human lives and livelihoods, safeguard infrastructure and property, ensure the continuity of human activities, and preserve environmental and cultural heritage in flood-prone regions. See figure on the right-hand page for an integrated flood defence system and its engineering measures.

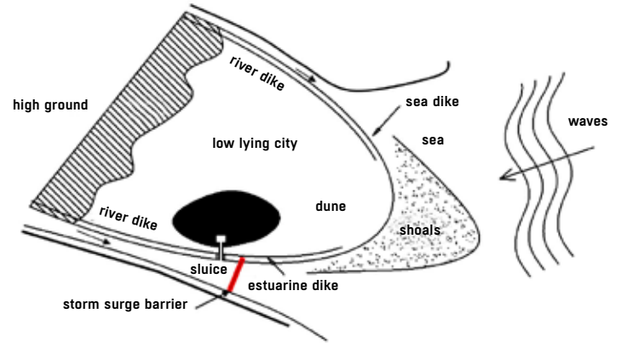
APPROACH – The design of flood defences is an iterative process that involves a multidisciplinary and risk-based approach. Engineers, urban planners, and ecologists collaborate to ensure robust and adaptive systems. Key important steps include:

1. *Hydraulic modelling*: simulating related water systems and flood scenarios under different conditions (e.g., high river discharges and storm surges which are associated with different return periods e.g. once in 100, 200, or up to 10,000 years) is essential in setting up hydraulic boundary conditions like design water levels and design waves.
2. *Risk assessment*: modelling, quantifying, and evaluating flood consequences for flood scenarios, including direct and indirect economic damages, and loss of life; weighing investment against potential damages and evaluating potential loss of life in view of societal (group) and individual risk to establish acceptable risk levels. On that basis, safety standards are formulated for the design by means of the return period of the design conditions (water level, wave, discharge) and/or acceptable probability of failure. The latter has been mostly applied in the Netherlands since 2017. [Risk Assessment, page 198]
3. *Development of alternative designs*: generating alternative measures that, most importantly, meet the water-retaining (primary) function (technical requirements). In considering additional/combined functions and stakeholder's wishes (functional requirements), a set of criteria is formed for alternative evaluation. The alternative that is technically most feasible, economical favourable and meets all criteria is selected for detailed design. [Multi-Criteria Analysis, page 190]
4. *Detailed design*: complying to national and international technical standards and/or building codes (e.g., Eurocodes, Dutch technical guidelines). Flood defences must have a sufficient height and structural and geotechnical stability given the design conditions.

APPLICATION
Flood defences are typically classified as structural measures, i.e. dikes (levees), dams, floodwalls, storm surge barriers and non-structural measures, such as retention basins, early warning systems, emergency responses, floodplain restoration (Table 1).

LIMITATIONS
Despite advances of flood defences, there are challenges in practice, including:

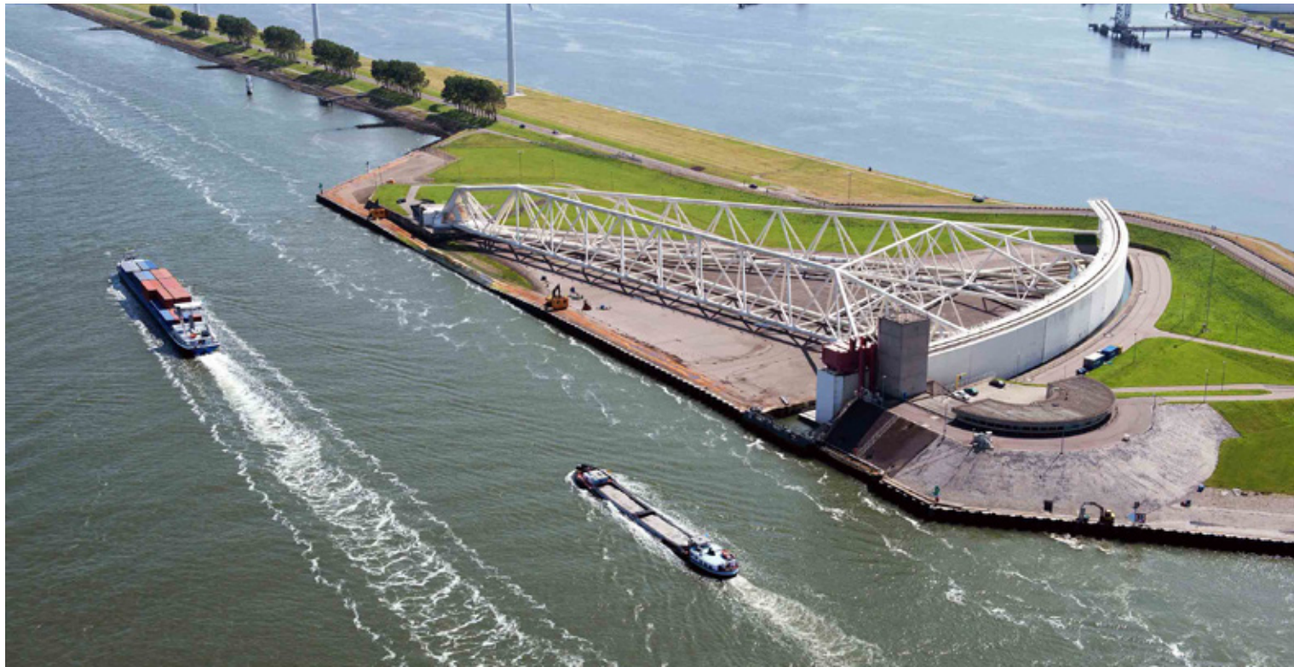
- **High initial investment and regular maintenance are required.**
- **Environmental impact due to disruption of ecosystems, sediment, and flow patterns.**
- **Residual risk due to unexpected weather patterns or excessive structural/ operational failures can cause catastrophic damage.**
- **Community complacency as relying solely on defences may reduce public awareness and preparedness, increasing vulnerability when systems fail.**



A flood defence system comprises different flood defences protecting a low-lying region. [Cong Mai Van]



Maeslantkering, Hoek van Holland, South Holland: storm surge barrier with movable arms of 210 metres each, with a height of 15 metres, which can withstand a flood wave of 5 metres NAP. The closing time is 2 hours. [© Rijkswaterstaat, Joop van Houdt]



5. *Adaptive design*: incorporating climate resilience by allowing future adjustments (e.g., heightening dikes, modular components, nature-based solutions in reducing hydraulic loads, etc.).

Cong Mai Van, TU Delft

FURTHER READING ■ Jonkman, B., et al. (2021). *Flood defences. Lecture notes, 4th edition* (2021). Delft University of Technology ■ *Journal of Coastal and Riverine Flood Risk*. TU Delft Open Publishing ■ Mai Van, C. (2010). *Probabilistic design of coastal flood defences in Vietnam.* PhD thesis. Delft University of Technology.

	Low-lying deltas	Upper deltas	Integration with urban public infrastructure added functions
Polder systems: dikes, dunes, storm surge barriers, dams, locks, pumping	flood defence, fresh water, salinity management, navigation	n.a.	traffic and transport
Upstream reservoir & dam	integrated water management	integrated water management	recreation, electricity
Tidal barrier, storm surge barrier, sluice, shipping lock	sea flood defence, salinity management, navigation	n.a.	traffic and transport
Flood rerouting, diverting channel/tunnel	diversion of flood water	n.a.	urban drainage, temporary storage
Retention area/Room for the river	cut off flood discharges, reduce high water levels	cut off flood discharges, reduce high water levels	recreation, greenery
Floodable parks	storage rainwater temporarily	storage rainwater temporarily	storage rainwater, recreation, greenery, public space
Elevated houses and roads	accepting flood, avoiding loss, evacuation possible	n.a.	traffic and transport, emergency services possible during floods
Flood-proof shelters	emergency response	emergency response	public space, public assets
Urban infrastructure along water	water-retaining walls	water-retaining walls	roads, walking routes, public space, underground parking places/plazas, quay walls, bird nesting places
Spatial planning and management	integrated water management, reduce vulnerability and consequences		

Table 1. Overview of flood protection measures and their application.



Doesburg, Gelderland: integration of flood defences in an urban context. [Mark Voorendt] **/ Top right: river dike along the Hollandse IJssel.** [Mark Voorendt] **/ Vlissingen, Zeeland: sea dike.** [Cong Mai Van] **/ Below: Deventer, Overijssel: multifunctional flood defence along the IJssel river.** [Mark Voorendt]



Infratecture

Tasks within transport and water infrastructure are mainly about functionality and cost control. This narrows the view to the most economical solution, leaving meaning and other social value out. How to challenge traditional management based on a minimalist programme of requirements?

PURPOSE – "Infratecture can be defined as the art of designing infrastructure: giving form and content to the foundation of our society; a foundation that allows society to function optimally in all its dimensions – spatially, socially, culturally, and economically. Infratecture is not a new or autonomous discipline; it is an attitude, a mentality, a way of thinking, an approach that all designers, planners, managers, clients, project managers, administrators, and other stakeholders in spatial planning can adopt." (Verheijen, 2021).

There is a lot of knowledge available about infrastructure as a design task. This knowledge is translated into manuals, guidelines, programmes of requirements, standard solutions, exemplary projects, and project descriptions; these are often based on functionality and efficiency, which gives direction to a design process for the realization of physical infrastructural objects that facilitate daily life.

For infratecture, a different route is chosen in which infrastructure not only serves as a facility which merely solves some mobility need for instance by a traffic engineering solution, but also creates sociological, cultural, ecological, and economic added value through integrated design. Solely problem-driven thinking and acting leads to autonomous design choices that separate the results from its environment. The design may solve the concrete problem at hand, but from a sustainable future perspective, opportunities in other areas are untapped. Understanding these is essential to enable the design of alternatives for a yet unknown future. That is what infratecture focuses on.

APPROACH – Infratecture distinguishes fifteen angles, which are discussed in a substantive and qualitative way within a multi- or interdisciplinary and professional discussion setting consisting of designers and experts (see Figure 1 and Table 1). The following attitudes are important:

- *Embrace complexity*: the (design) 'task' is many times more complex than the actual (design) 'question' will be able to create social added value. Through intensive cooperation, many more (social) benefits can be achieved from investments in infrastructure than just those based on one's own background, knowledge, skills, habits, and language.
- *Challenge on content*: managing professionals from different disciplines is difficult. Challenging them in terms of content is the way to arrive at a common language, to get on course of a shared vision, and to allow a variety of insights and inputs to come together in a synergistic way as a common foundation under the individual contributions. Which angles are relevant and what significance do they have in the assignment?
- *Aspire to create and name value*: this should occur beyond a strict functional program of requirements and the expectations of stakeholders. Good infrastructure has current and future value.

APPLICATION
Infratecture facilitates multi- or interdisciplinary design teams in the interpretation and translation of a design question into a value-driven design ambition for infrastructure and public space assignments.

LIMITATIONS
Infratecture assumes an open attitude of a client about the problem definition or design question without a completely rigid program of requirements as starting point.

Marc Verheijen, Municipality of Rotterdam

FURTHER READING ■ Bil, H., & Teisman, G. (2017). *Zit je vast? Maak het complexer! Hoe complexificeren als managementstrategie Stationsplein Oost nieuw leven gaf.* Eburon Academic Publishers ■ De Urbanisten & Verheijen, M. (2015). *Functional Ambiance. Een ontwerpmethode van de buitenruimten.* Hogeschool Rotterdam ■ Verheijen, M. (2015). *Infratecture. Infrastructuur als ontwerpopgave.* Nai010 Uitgevers.

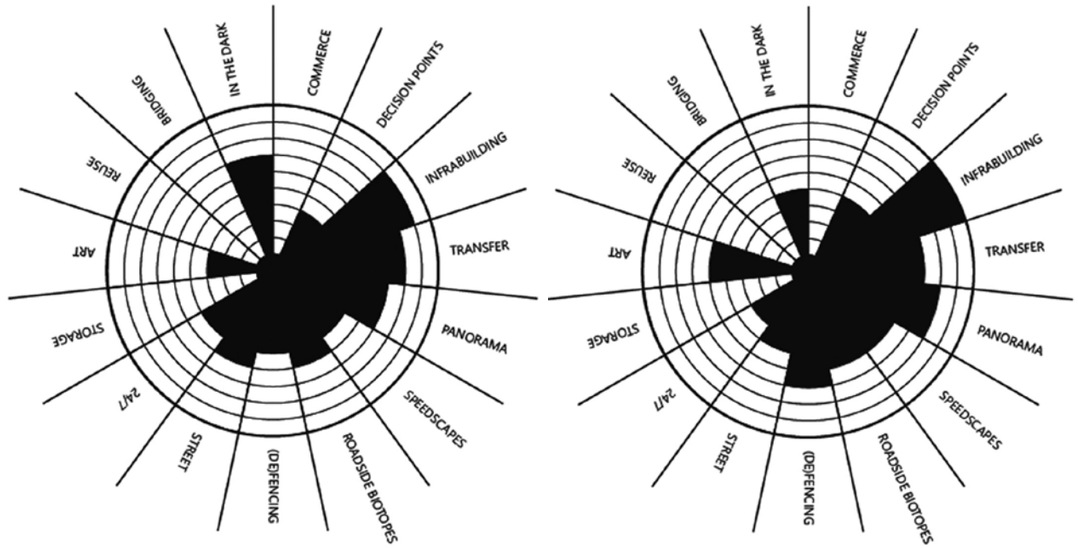


Figure 1. Metro stations Hoekse Lijn: the spider graphs of Hoek van Holland Strand and Steendijkpolder show that the so-called infrabuilding angle is most dominant. The beach station differs as end station by its character (art, panorama), location ((de) fence) and use (24/7) from the urban station Steendijkpolder with an emphasis on other design ambitions and objectives due to its location and use (transfer, street, 24/7, in the dark). The spider graph is a visual aid for the dialogue to reveal the essence of the assignment. [Marc Verheijen]

Angle	Aspects
Transfer	transfer point, humanity, walk, walking route, satisfiers dissatisfiers, mobility flows
Infrabuilding	hyper urbanization, behavioural change, co-dependencies, symbiosis, typology
Decision points	identity, distinctness, orientation, appropriation
Commerce	commerce, retail, advertising, run shopping, service, third flow of funds
In the dark	geotechnics, safety, sensory aspects, light, smell, sound, experience, reassurance
Bridging	icon, identity, technique, combined action
Reuse	lifespan, service life, future value, downgrading, interventions, smart and sublime, reuse, bottom-up, community driven
Art	art, exhibition space, creating conditions, enrichment, disruption, critical, soul, social meaning
Storage	orientation, standstill, parking, parking facilities, running line, urban fabric
24/7	24/7 mentality, no-tech, low-tech, high-tech, 4D thinking, reliable, robust, disruption scan
Street	diversity, functionality, ambiance, functional ambiance, together, city
(De)fence	combination, added value, view, fronts
Roadside biotopes	biotopes, long stretches, left-over space, corridors
Speedscapes	perception, speedscape, distance, balance
Panorama	panorama, perception, discover, experience, appreciate

Table 1. Overview of infratecture angles and defining aspects.

Integrated Bridge Design

Designing a bridge means seeking structural stability within a complex web of spatial, functional, technical, environmental, cultural, and social contexts. A good design endures over time while responding to new expectations and contributing added value beyond its utility.

PURPOSE – A bridge is one of the oldest and most enduring forms of infrastructure; some bridges dating back to Roman times are still in use today. As Vitruvius defined in antiquity, a structure is only truly valued if it embodies these three qualities: *firmitas* (strength), *utilitas* (utility), and *venustas* (beauty). A bridge spans a gap and carries loads, fulfilling clear functional and structural roles. They are often landmarks – symbols of civilization – shaped by and shaping their cultural and social context. Their beauty lies not only in form, but in the intangible experience bridges offer: emotion, memory, and meaning.

To meet Vitruvius' triad in a balanced way, architects and engineers must collaborate closely when designing a bridge (Figure 1). The '*what*' and '*for whom*' of a bridge relate to the conceptualisation of its purpose and use; the '*how*' refers to the process of finding an acceptable, buildable solution. Design decisions are shaped by how forces act on the structure, how boundary conditions are addressed, how the bridge affects its environment, and whether the ambitions of the client can be realised within budgetary constraints.

An integrated and interdisciplinary approach is essential from the earliest stages of the design process, informed by thorough analysis and guided by the cohesive and iterative development of both technical and architectural aspects. The architectural design cannot be separated from the structural design – both inform each other, and forward and backward thinking are equally necessary. Clear communication with the client, and where possible with future users and local residents, fosters shared understanding, commitment, and appreciation.

APPROACH – The design process consists of the following steps.

1. *Context analysis*: analyse the geographical, historical, environmental, and social context of the location; interpret the ambitions and wishes of the commissioner alongside the programme of requirements in a balanced way.
2. *Programme and constraints*: map the functional arrangement of different user types, including physical constraints such as parapets, fenders, and lighting; define boundary conditions such as ground and water levels, clearances (width and height), and soil conditions; and draft a scaled cross-section of the gap to be spanned – including its landings – which provides an essential starting point.
3. *Alignment*: determine the horizontal alignment based on existing or preferred routes and visual connections; define the vertical alignment (top of deck) using acceptable gradients for all user types; draw the required clearances underneath the deck, considering the assumed structural depth; and identify potential support locations accordingly (Figure 2).
4. *Typology*: develop a basic structural scheme including supports, moment lines, and boundary conditions as the basis for selecting

APPLICATION
Spans: water, roads, railways, uneven terrain, buildings, utilities, other physical obstacles. Carries: motorised traffic (cars, trucks, trams, trains), active mobility (cyclists, pedestrians, wheelchair users), animals, landscape, waterways, technical utilities.

LIMITATIONS
In seismically active regions, bridge design must comply with dedicated codes and standards. Extremely large spans (> 2 km) may prove prohibitively expensive, making a tunnel more appropriate. Similarly, high-density urban environments, mountainous terrain, or deep waters limit the feasibility of a bridge solution.

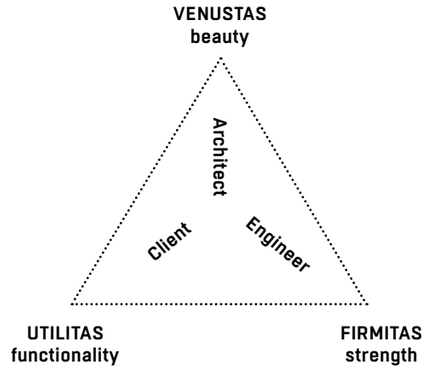


Figure 1. The architect, engineer, and client as representatives of venustas, firmitas and utilitas. The architect seeks to add value by creating a design beyond the functional requirements. An integrated approach and interdisciplinary collaboration are essential due the complexity of the contract, design, construction, and environment. [Joris Smits]

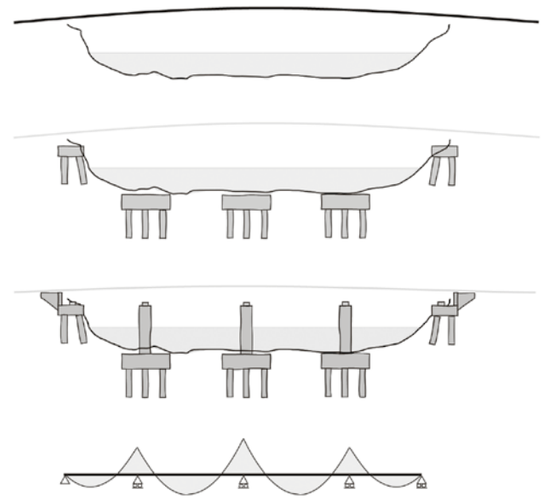


Figure 2. Vertical alignment, foundation, supports and moment line of forces. [© Ney & Partners] / Below: De Lentloper by Ney & Partners, Nijmegen. [© Thea van den Heuvel]



an appropriate bridge typology (Figure 3 and Table 1). This guides decisions on key dimensions and material choices, always in relation to budget constraints and long-term maintenance.

5. *Concept design*: translate the chosen alignment and typology into a bridge concept that is fully integrated with its surroundings and informed by contextual analysis, project ambitions, and functional requirements, and inspired by imagination, fascination, and curiosity; explore your ideas through many quick sketches and rough physical models since drawing is a way to educate the eye in what to see.
6. *Preliminary design*: develop the architectural and structural aspects into a coherent preliminary design, in which the balance between form, structure, material use, and force distribution becomes legible in the main span and the approaches; and use drawings, digital models, and structural calculations to test and refine the design — with material efficiency as a key driver for sustainability and cost control.
7. *Detailed design*: develop the preliminary design into a detailed design in which all parts are specified, dimensioned, and materialised; structural solutions are fully worked out, while architectural elements — including colours, finishes, and textures — are clearly defined. At this stage, cost estimation can be finalised and preparations for construction can begin.

Joris Smits & Stijn Joosten, Ney & Partners

FURTHER READING ■ Ney, L. (2014). *Nijmegen: Designing the 'City Bridge'.* Van Tilt Publishers ■ Ney, L. (2019). *Bridging. By foot and bicycle.* Ney & Partners ■ Smits, J. (2019). *The art of bridge design. Identifying a design approach for well-integrated, integrally-designed and socially-valued bridges.* TU Delft.

	Typical span (m)	Advantages	Disadvantages
Slab	5 ~ 10	minimalistic; non-intrusive in landscape; minimal height, suits low clearance; fast prefabrication	material inefficient beyond ~10 m; visually plain; not suitable for longer spans
Beam	10 ~ 50	simple, predictable, easy to design; non-intrusive in landscape; fast prefabrication possible; suitable for reuse in circular design	high structural depth of deck; visually bulky or plain; becomes inefficient for longer spans
Truss (Warren)	20 ~ 150	strong, stiff; material-efficient, pure compression and tension; easily adaptable	intrusive, bulky; high maintenance (joints); industrial look; complex detailing
Tied-arch	30 ~ 300	elegant, classic look, architectural potential; efficient, pure compression and tension; self-anchored; no thrust on abutments; can be prefabricated and placed in short time	complex detailing at arch-deck connection; large, prefabricated parts; transport challenges; sensitive to non-uniform loading patterns; maintenance of arch and hangers
Cable-stayed	40 ~ 1.100	modern, efficient, pure compression and tension; suitable above roads/ rail with staged construction	must be built in situ; sensitive to cable vibration; maintenance of cables and pylons is critical
Suspension	500 ~ 2.000+	enables extreme spans; visually light and transparent	complex and costly in situ construction sequence; large anchorage blocks, good soil, rock conditions needed; aerodynamically sensitive; maintenance of cables and pylons is critical

Table 1. Bridge typology characteristics.

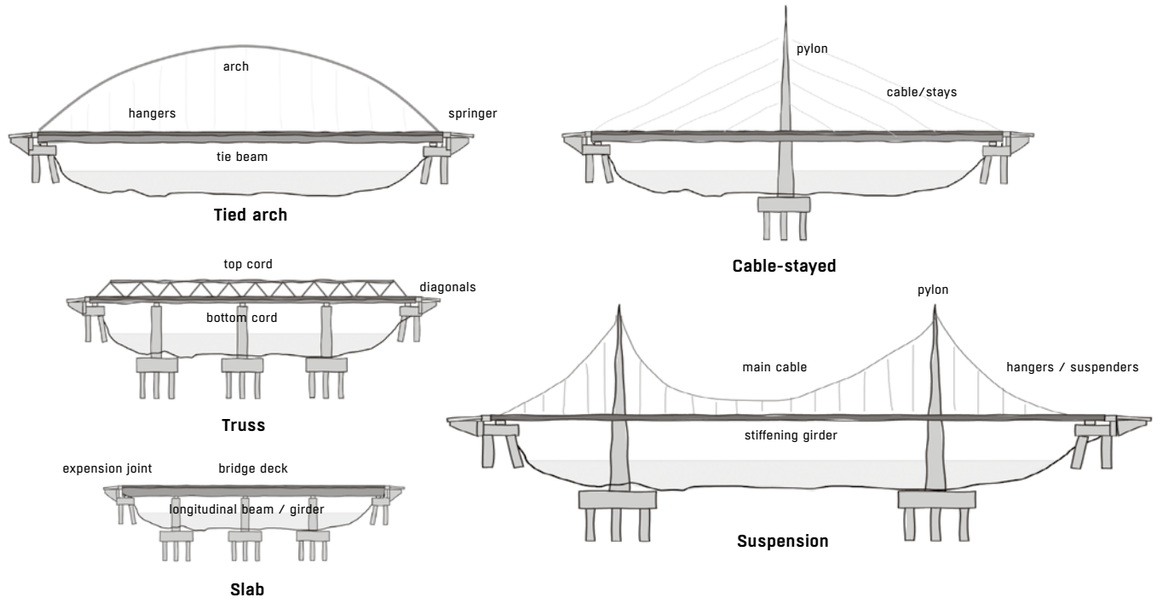


Figure 3. Most common bridge typologies. [© Ney & Partners] **/ Lissabon: cable-stayed section of the Vasco da Gama bridge designed by Armando Rito. The total length is 17,185 m of which 12,345 m for the bridge structure. The width is 30 m and its navigation clearance is 47 m for the main bridge. The longest span is 420 m.** [CC Rob Oo]



Integrated Infrastructure Design Method

In the 1960s, designers separated spatial design from engineering approaches, believing common methods – strongly relying on natural science models – were too straightforward to foster maximum creativity. However, this shift to separate design processes ultimately failed to meet the designers' expectations.

PURPOSE – The integrated infrastructure design method re-unites spatial and engineering design, combining technical, aesthetic, environmental, and social considerations into a single cohesive process. [The Reconciliation of Spatial Design and Engineering, page 132] It is transdisciplinary and holistic, attempting to include all the elements necessary for an optimal design. The focus is on maximising social value and spatial quality, while safeguarding the robustness of the intended system. The complexity of designing infrastructure requires this systematic and logical approach to streamline the course of activities and make the design process effective and transparent. Without this cross-disciplinary integration, the design process risks becoming insular and less responsive to the complexity of real-world contexts.

APPROACH – The main design stages as defined by Roozenburg and Eekels (1995) are essential and logical steps in an efficient and effective design process. Designing is conceived as a complex, personal, creative, and open-ended skill (Van Dooren et al., 2013). The use of lenses can guide the exploration as well its conceptualisation. [Integrated Infrastructure Design Lenses, page 182] Therefore, in the method, the definition and verification of the requirements only takes place after the developments of concepts during early design stages. The iterative nature offers possibilities to experiment and to learn and improve earlier design steps, which can be obtained by combining both design approaches. In the more detailed engineering design cycles, the approach can be more straightforward and less integrated.

The integrated design method has seven design phases, as shown in the figure on the right-hand page. The process is iterative and cyclical, involving experimentation and ongoing evaluation. The depicted integrated approach is completed with the realisation, operation and second life stages.

Mark Voorendt, TU Delft

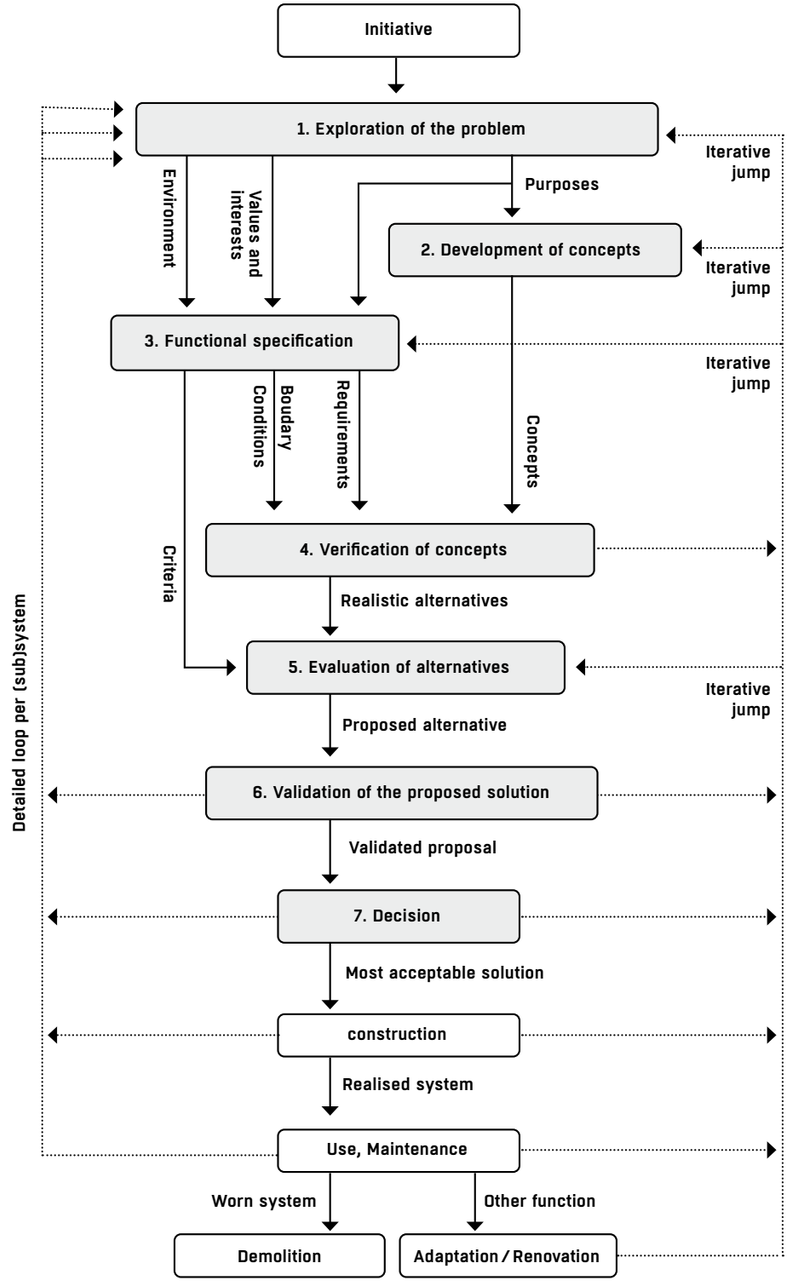
APPLICATION
Design of infrastructure, public space design, urban design, regional design, environmental design, design of multifunctional flood defences.

LIMITATION
The integrated approach is a means to obtain aspired social values. Especially apprentice and novice designers can benefit from the described approach, while experienced designers have much less need for a prescribed procedure.

FURTHER READING ■ **Roozenburg, N.F.M., & Eekels, J. (1995).** ***Product design: Fundamentals and Methods.*** **2nd edition, John Wiley & Sons Ltd ■ Van Dooren, E., Boshuizen, E., Van Merriënboer, J., Asselbergs, T., & Van Dorst, M. (2014). Making explicit in design education: generic elements in the design process.** ***International Journal of Technology and Design Education, 24,*** **53–71 ■ Voorendt, M.Z. (2017).** ***Design principles of multifunctional flood defences.*** **Doctoral dissertation. Delft University of Technology.**

- Functional, technical, and architectural well-designed and well-built structures.
- Appropriately integrated in a larger transport or water system or network.
- Appropriately embedded in their spatial and environmental context.
- Connect different scales and bridge morphological barriers.
- Connect regions and places, cities and neighbourhoods, communities, and people.
- Support societal functions and programmes, economic sectors, and markets.
- Enable users to perform their present and future social and economic activities.
- Contribute to accessibility, liveability, economic competitiveness of cities and regions.
- Contribute to sustainable and broad prosperity and safety for societies.

Within design education, the above definition is used for integrally designed infrastructures.



Integrated design method as developed in the TU Delft minor programme Integrated Infrastructure Design (IID). [Voorendt, 2017]

1. EXPLORATION OF THE PROBLEM: understanding the assignment's purpose and values, identifying stakeholders, and recognising relevant contextual factors.

2. DEVELOPMENT OF CONCEPTS: generating ideas or concepts to explore ways to reach the aspired value and refine the problem and design goals. Creativity is given ample space because the designer is not consciously or unconsciously limited by requirements that have already been formulated.

3 & 4. VERIFICATION OF CONCEPTS: the assessment of the feasibility of the created concepts by defining and verifying requirements, taking boundary conditions into account.

5. EVALUATION OF THE ALTERNATIVES: design alternatives are evaluated and selected based on criteria important to the client and stakeholders. This step may further clarify the problem, potentially prompting a return to earlier phases.

6. VALIDATION OF THE PROPOSED SOLUTION: the selected alternative can be validated to ensure that it matches with the initial needs of the client.

7. Finally, a decision is made to proceed with the chosen design or to revisit earlier steps for improvement.

METHODS – TECHNIQUES – STRATEGIES

Integrated Highway Design

Highways connect and divide. Their presence is ubiquitous and strongly associated with economic development and growth. Since car ownership became an individual goal of status and success and an attribute of modern life, the demand for more infrastructure became insatiable. However, its environmental burden, spatial impact and high financial costs ask for another approach. How to implement this?

PURPOSE – We rarely look at them – unless they crumble. Highways are so embedded in our urban landscapes that we forget they were once designed. Engineered for speed and flow, they brutally cut through cities with engineered precision, often leaving behind air pollution, noise, barriers, and undefined edges. But what if we reclaimed them as spatial instruments and design them with pride? Across the world, highways are being rethought – not only as mobility corridors, but as opportunities for modal shift, climate adaptation, and neighbourhood revitalization. This method proposes seven paradigms through which to design them differently. Not to romanticize asphalt, but to restore a sense of agency and imagination in shaping what highways could do to, and for, the city.

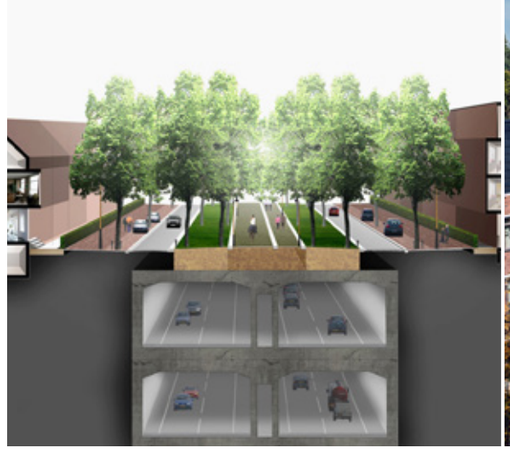
APPROACH – This design method draws on *seven spatial paradigms* identified through research by design and comparative cases.

1. *Conductor – Infrastructure as a sustainable mobility facilitator*: highways canalize huge fluxes of cars, yet, when mitigating its environmental impact, they can support multimodal and healthy movement when spatially restructured. In *Maastricht (the Netherlands)*, the A2 was sunk into a tunnel, allowing the Groene Loper – a new linear park – to restore urban continuity, foster soft mobility, and create space for 1,100 new homes. The Calle 30 in *Madrid (Spain)* integrated a park of 6 km and 253,000m² of recreational facilities, by tunneling 55 km of ring road. Infrastructure serves the city when it no longer severs it.
2. *Infra-Structure – Infrastructure as armature for development*: highways can guide territorial development. In Flight Forum *Eindhoven (the Netherlands)*, the road alignment frames an innovative industrial campus. Along the A4 in *Schiedam (the Netherlands)*, road works are combined with sport fields, wildlife crossings, and a neighbourhood meeting center. Highways can become social scaffolds – not scars.
3. *Artefact – Infrastructure as architectural object*: when thoughtfully designed, infrastructure can create identity and experience. The Nordtangente in *Basel (Switzerland)* not only stacks car lanes, but also trams and public space across three levels, integrating sport facilities and neighbourhood space. In *Lummen (Belgium)*, a turbine junction is reimagined as a landscape spiral. These projects show how expressive engineering becomes urban design.

APPLICATION
This method is applicable for: (a) redeveloping highway segments in or near urban areas; (b) linking infrastructure renewal with urban, ecological, or social ambitions; (c) large-scale, phased infrastructure projects where spatial quality and multifunctionality are part of the brief; (d) contexts requiring not just movement, but meaningful integration.

LIMITATIONS
Enabling conditions are needed, and without these the best intentions remain on paper. Despite its flexibility, the method requires:

- **Strong governance: without a public lead, spatial ambition risks being diluted.**
- **New cooperation models: multiple agencies, fragmented ownership, and layered policy levels must be bridged, including structural participation with citizens and grassroots movements.**
- **Sustainable financing: spatial quality and ecological performance must be funded beyond technical budgets.**
- **Legal clarity: spaces beneath or beside highway corridors often have complex ownerships and lack integrated activation frameworks.**





Conductor: two-level tunnel and urban development of De Groene Loper for the A2 through Maastricht by the Avenue2 consortium, made up of Ballast Nedam, Structon, West 8. [© West 8 / © Aron Nijs]



Infra-Structure: the Willem-Alexander sports park, designed by MoederscheimMoonen architects, on the roof of the Kethel tunnel (A4) near Schiedam. [© MoederscheimMoonen] **/ Artefact: Dreirosenbrücke, a two-level bridge with usable space, designed by Steib+Steib architects, as part of the Nordtangente A3, Basel.** [CC Baenziger Partner AG – Theiler Druck AG / © Ruedi Walti]





4. *Test Space – Infrastructure as typological laboratory*: highway edges can incubate new architectural typologies. In *Almere (the Netherlands)*, noise walls double as housing façades. The *Norwegian Public Roads Administration* has upgraded the Norwegian Scenic Routes with architecture and art, highlighting the highway landscape with architectural pavilions and viewpoints, designed by more than 50 architects, landscape architects, designers and artists. In *Amsterdam (the Netherlands)*, A8erna transforms a viaduct's underside into space for sports, facilities and recreation. This way, infrastructural presence can be a catalyst for typological creativity and innovation.
5. *Soft Infrastructure – Infrastructure as ecological corridor*: hard infrastructure can integrate green and blue systems and restore ecological missing links. The A11 in *Bruges (Belgium)* integrates landscape, water, and biodiversity into its design. *Vienna's* outer ring A21 *(Austria)* uses berms and habitat corridors to reduce noise and increase ecological value. Here, infrastructure supports urban and ecological metabolisms, not just traffic.
6. *Adaptive – Infrastructure as future-proof framework*: today's highways must respond to uncertainty, in mobility, technology, and climate. *Helsinki's* city boulevards *(Finland)* strategy offers a compelling model: radial highways entering the city are gradually converted into mixed-use urban boulevards – integrating housing, public transport, and green space over time. Rather than an abrupt overhaul, the approach enables stepwise redevelopment, aligning infrastructure with long-term social, ecological, and spatial ambitions. The Skygarden in *Seoul (South Korea)* modified the 938-meter-long highway viaduct to create a new walkway with 254 species of trees, shrubs and flowers. Designs must thus allow for phased transitions and shifting societal priorities.
7. *Oversize – Infrastructure as multifunctional envelope*: road sections can host more than traffic. The SMART tunnel in *Kuala Lumpur (Malaysia)* combines motorway and stormwater functions in one tube. In *Antwerp's* capping of the R1 ring road *(Belgium)*, proposals include geothermal loops, slow mobility, and water buffering within one integrated section. Let's design these 'supersized' corridors as resilient carriers of multiple fluxes.

Maarten Van Acker, University of Antwerp

FURTHER READING ■ Coppens, T., Van Acker, M., et al. (2021). A real options framework for adaptive urban design. *Journal of Urban Design, 26* (6), p. 681-698 ■ Smets, M. & Shannon, K. (2016). *The landscape of contemporary infrastructure*. nai010 ■ Mumford, L., (1963). *The highway and the city.* Harcourt, Brace & World ■ Van den Boomen, T. et al. (eds.) (2017). *Highway x city: the future of the urban ring road.* BNA, Public Space.





Test Space: house facade as a sound wall for ground-bound homes in Almere, designed by TANGRAM architecture and urban landscape. [© TANGRAM] **/ Adaptive: the Skygarden in Seoul, a former inner-city highway transformed into a public 1,024-metre-long park, designed by MVRDV Architects.** [© Ossip van Duivenbode]



Soft Infrastructure: spatial integration of the 12-km long new motorway A11 in the polder landscape, designed by Bureau Bas Smets, connecting Bruges and the northwestern coastal area of Flanders. [© Michiel De Cleene] **/ Oversize: Ringpark Het Schijn by design team OMGEVING and De Urbanisten, one of the seven parks covering the ring road R1 in Antwerp.** [© OMGEVING – De Urbanisten]





Nature-Inclusive Infrastructure

The world of transport depends on connections and speed. However, in its shadow is another world to discover in which plants and small animals could also make use of infrastructure. Nature-inclusive design can help flora and fauna in a more active way.

PURPOSE – Nature-inclusive design can stimulate biodiversity and improve the underlying ecosystem, by making use of the characteristics of transport and water infrastructure and by considering a number of nature principles.

Roads, railways, and canals not only connect people but also populations of plants and animals. The verges of the infrastructures are quiet and plant-rich surfaces – often rarely accessed by humans – which can connect places. Railway yards are a paradise for botanists, as seeds come from all directions on the trains. Infrastructure in the city is intensively used by many other species than just humans.

It is about creating favourable conditions for a biotope to maintain and survive so that generations can succeed each other. This involves migration, food, water, safety, and reproduction. Although functionality is a dominant factor in infrastructure design, the smart use of the basic principles of nature-inclusive design can contribute to such a biotope. In contemporary infrastructure planning, ecological and environmental values are recognized and examined so that they can be considered in the design. Existing infrastructure and disused infrastructure can also be used to create a more natural environment, both to create the required biodiversity as well as improve the quality of the living environment of humans and animals.

APPROACH – Infrastructure can offer the following opportunities to apply principles of nature-inclusive design.

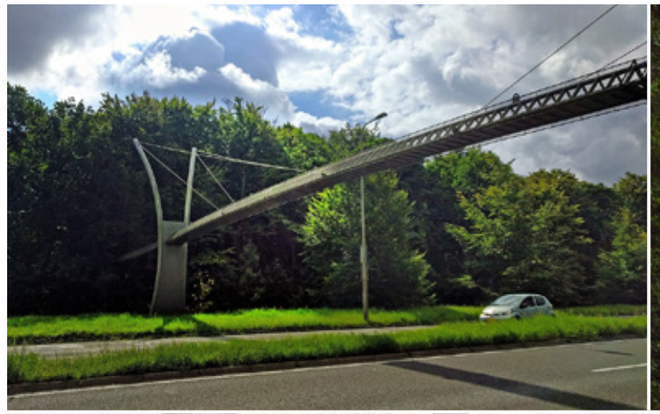
- *Make use of its connecting and conductive character to facilitate migration and foraging:* line infrastructures, such as roads, railways, and waterways, can provide space for nature through plant-rich verges, while it can also connect nature-rich areas. A wildlife crossing ('ecoduct' or tunnel) is a deliberate link in the connection of natural areas that are intersected by other infrastructures. Many small mammals and insects use our infrastructure to migrate. It offers foraging opportunities for insects, birds and small mammals and therefore also for birds of prey. Tree structures along the infrastructure give bats the opportunity to navigate. To increase safety and thus survival chances for deer crossing a waterway, so-called fauna exits can be placed on the banks. There are similar solutions for smaller mammals such as hedgehogs. Fish passages like the new fish migration river in the renovated Afsluitdijk or the temporary opening of the several discharge sluices in Zeeland can overcome barriers between salt- and freshwater to attract fish and help them migrate. Within cities it is important to connect the highly-fragmented nature to create reasonable chances of survival for smaller mammals. The continuity of the space to move and the increase in scale of the living space are design principles that also consider the safety of the animals.
- *Use structural works as potential hiding and breeding grounds:* because we started making stone buildings and bridges, species such as the swift, starling and various species of bat came to our country. These

APPLICATION
Line infrastructure: roads, railways, and waterways. Structural works: bridges, viaducts, retaining walls, quays, discharge sluices.

LIMITATIONS
Within highly-fragmented areas with insufficient connection possibilities, little migration is possible. An environment with intensive car traffic and few opportunities for safety can lead to many animal casualties.



Top: wildlife crossing Groene Woud over the A2 north of Best, Brabant. [© Rijkswaterstaat, Rob Poelenjee] **/ Middle: The Hague: squirrel bridge over the S101 near the Haagse Bos.** [CC Rudolphous / CC S.J. de Waard] **/ Bottom: Groningen: niches in the concrete of the Kattenbrug in which bats live. Designed by Korth Tielens Architecten and DS landscape architects.** [© Dennis de Smet]





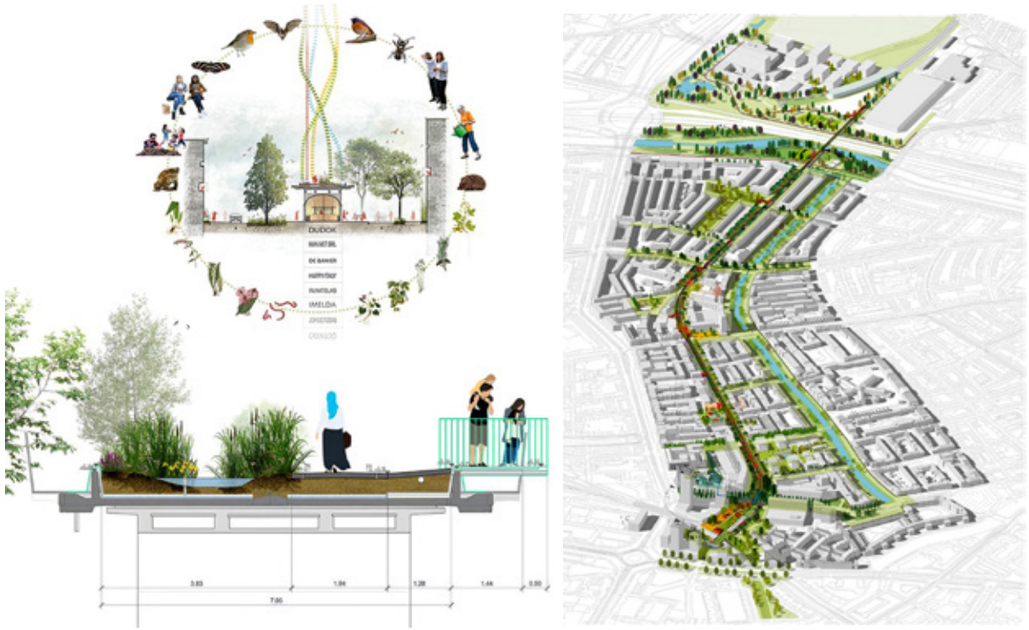




rock dwellers crawled into the cracks and holes that were still in the buildings at the time. Modern buildings are smooth and without cracks. To find nesting opportunities, such species depend on attached or built-in nesting boxes. Integrating nesting opportunities in buildings is now fairly common. At structural works like bridges nesting bowls can be made for the house martin, such as at the bridge over the Houtrib sluices near Lelystad. So, leave cracks and ledges open for bridge or viaduct constructions. Use niches or nesting bowls in retaining walls and quays. This ensures good accessibility, shelter, and safety for animals.

Maike van Stiphout, DS landscape architects

FURTHER READING ■ Van Stiphout, M., & Lehner, M. (2020). *First guide for nature-inclusive design.* DS Landscape Architects ■ Van Stiphout, M. (2023). *Second guide for nature-inclusive design.* DS Landscape Architects (2023) ■ Vink, J., Vollaards, P., & De Zwarte, N. *Building urban nature. Towards a Nature-inclusive Architecture,* Nai Publishers (2024).



Hofbogenpark, Rotterdam: design for a city park on a disused railway viaduct. [© DS landschapsarchitecten, De Urbanisten, De Dakdokters]





The Lentloper, Nijmegen is home to the largest colony of barn swallows in the Netherlands. The rebate between the underside of the bridge deck and the pillar was initially intended to compensate for intolerances of the slightly curved concrete deck in relation to the various pillars. Now it is an ideal place for nesting. Design by Ney & Partners. [CC Michiel Verbeek / © Ney & Partners]



Bus station Maankwartier, Heerlen: a green canopy with a possibility for birds to nest and for people to cool down. Designed by Michel Huisman. [CC Nanda Sluijsmans] **/ Hofbogenpark, Rotterdam: design and test for a city park on a disused railway viaduct** [© DS landschapsarchitecten, De Urbanisten, De Dakdokters]







Design strategies for Infrastructure-Entangled Spaces

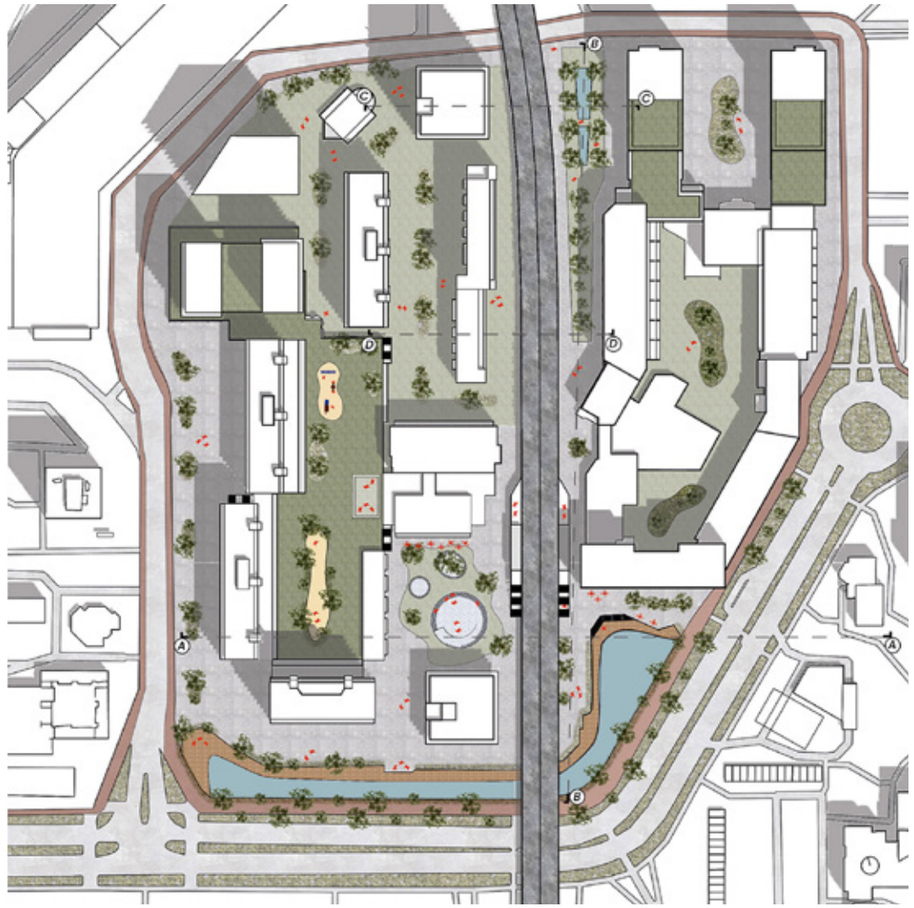
Metropolitan regions and large cities are shaped by extensive, multimodal transport infrastructures. While facilitating connectivity across multiple spatial scales, these networks often fragment the urban fabric, sever ecological corridors, and isolate neighbourhoods. This raises a pressing question: can the residual, interstitial, and overlooked spaces along mobility corridors be reimagined through design to restore continuity and generate new spatial, ecological, and social value?

PURPOSE – Transition zones at the margins of metropolitan mobility infrastructures, such as ring roads, motorways, and railways, constitute a fragmented and frequently overlooked element within the contemporary urban environments. These in-between spaces, slumbering between heterogeneous systems of movement and the consolidated urban fabric, encapsulate both the constraints and the possibilities of more contemporary-wise approaches to urban transformations. Often emerging as an unforeseen consequence of the rigid functional model proposed within the 'modern city' of the CIAM approach, they represent pressure points where ecological fragility, spatial discontinuity, and socio-economic fragilities converge. Simultaneously, they present opportunities to reimagine the relationship between infrastructure and public space, between systems of flow and places of interaction. As urbanisation accelerates and sustainable sensitivity intensifies, the need to develop more virtuous design strategies for these fringes demands renewed attention, both as critical challenges and as catalysing sites for innovation.

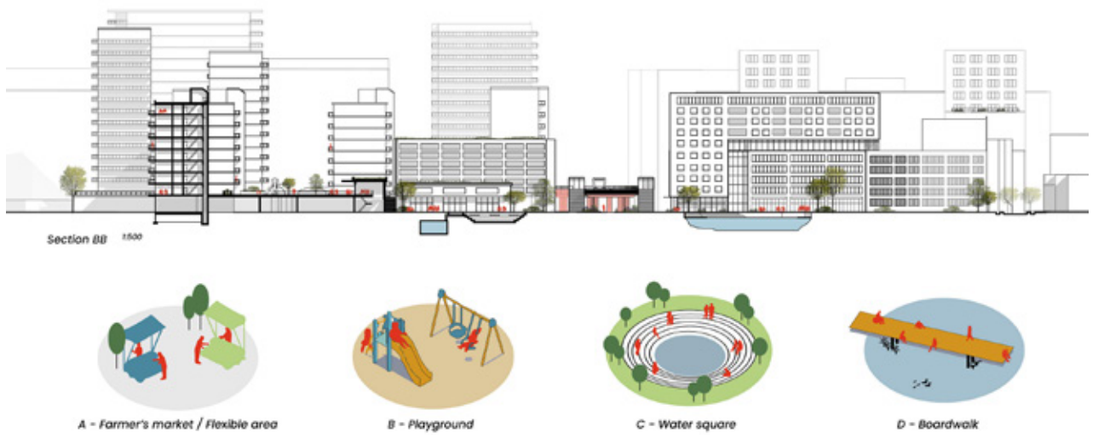
The MSc2 studio Architecture & Urban Design at the Faculty of Architecture & the Built Environment, TU Delft, has positioned these marginal conditions as an important subject of investigation. Through various projects, the studio consistently addressed the role of design, particularly focusing on the spatial performance of natural and built environments adjacent to mobility infrastructure like multimodal hubs and residual spaces. The developed method stimulates systemic thinking and cross-scalar coherence, combining urban and peri-urban reasoning with site-specific actions. It is embedded within a broader framework of transition values, including those promoted by the New European Bauhaus (NEB) initiative: sustainability (ecological balance and circularity), inclusiveness (accessibility and affordability), and aesthetics (inspirational and emotional power of design and beauty beyond functionality).

APPLICATION
The method is most effective for transition zones along motorways, railways, and major urban roads which often suffer from spatial fragmentation, ecological discontinuity, and social detachment. Interventions need to operate across different scales – such as territorial, urban, and architectural – and need to find where a balance between environmental performance, spatial coherence, and urban-public space. This method is well-suited for interdisciplinary efforts involving spatial designers, urban policymakers, and infrastructure agencies aiming to reimagine the role of large-scale mobility systems in shaping the future city.

LIMITATIONS
The method may prove less effective in contexts marked by tight regulatory constraints, incremental spatial change, or siloed disciplinary practices. Its speculative and cross-scalar nature can appear misaligned with short-term engineering goals or narrowly defined planning agendas. In such cases, more focused tools – such as typological studies, participatory processes, or regulatory design frameworks – may better address context-specific challenges and implementation timelines.



Zoetermeer – Meerzicht 2070: master plan, section, and public space themes of the student project Densify, Activate, Recreate by Rysa Braganza and Desiré Verlaan. [Braganza & Verlaan, 2024, Studio theme Zoetermeer Railway and Highway Areas, academic year 2023-2024, MSc2 Studio Architecture & Urban Design]

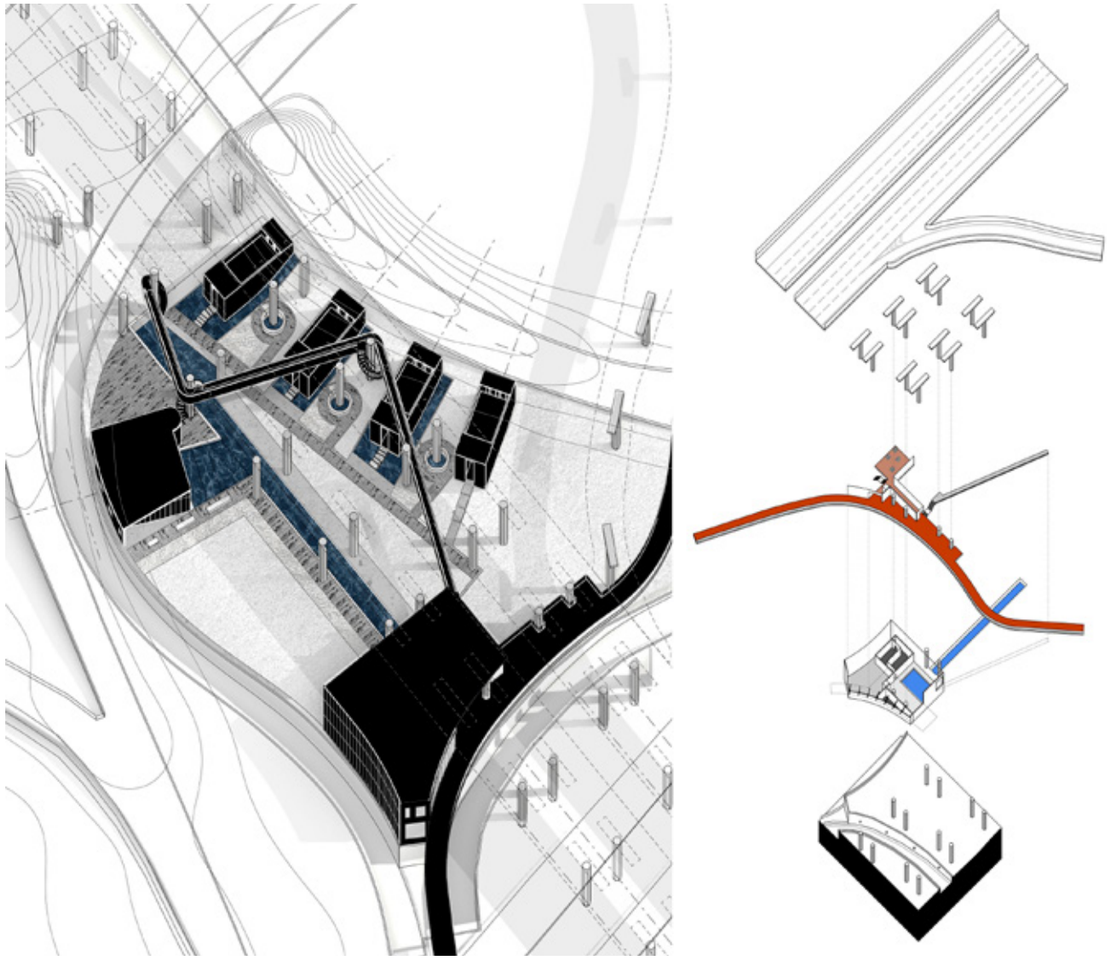


APPROACH – The method has been structured into three phases, integrating analytical and design practices and employing multiple scales. It enables a layered and responsive approach to transitional infrastructural spaces.

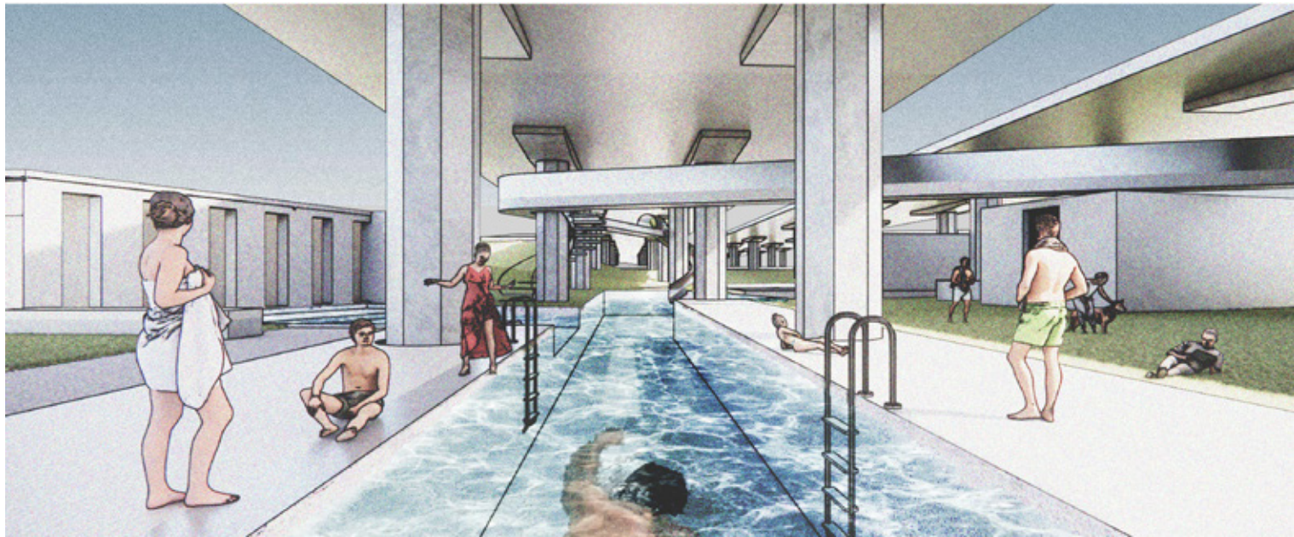
1. *Critical mapping & taxonomy of spaces*: the design-driven research begins with the production of layered spatial mappings and a structured taxonomy of residual spaces and potential opportunities. It is based on the analysis of the urban environment at multiple scales and focuses on the intersections between infrastructure and ecological systems, public space fragmentation, hybrid land use and edge conditions, and on the typologies of leftover, in-between, and transitional areas.
2. *Strategic scenario development*: urban and architectural design strategies are formulated in order to aim at reconfiguring the spatial dynamics of infrastructure-dominated areas, and to produce alternative visions and scenarios for future transformations. These strategies encompass the reinforcement of ecological corridors and blue-green infrastructures; the reimagining of multimodal nodes as urban polarities; the creation of new urban centralities within infrastructural interstices; and the articulation of spatial relationships between subterranean systems and their above-ground counterparts.
3. *Translation*: the strategies are ultimately translated into design proposals operating at both the urban and architectural scales. These interventions investigate new forms of public space emerging along infrastructural edges, reconfigure interfaces between mobility flows and local accessibility, explore the spatial materialisation of ecological infrastructures, and test programmatic hybridisations – such as the integration of transport, housing, and recreational uses.

Roberto Cavallo, TU Delft & Nicolò Chierichetti, Politecnico di Milano

FURTHER READING ■ Berkers, M., De Boer, H., Buitelaar, E., Cavallo, R., Daamen, T., Gerretsen, P., Harteveld, M., Hinterleitner, J., Hooimeijer, F., Van der Linden, H., & Van der Wouden, R. (2019). *De stad van de toekomst: tien ontwerpvisies voor vijf locaties, verbeelding voor een vierkante kilometer stad = The city of the future: ten design strategies for five locations, visualizations for a square kilometre of city.* BNA Onderzoek, Uitgeverij Blauwdruk ■ De Boer, H., Van den Boomen, T., Chorus, P., & Hinterleitner, J. (eds.). (2014). *Onder weg!: vijftien ontwerpen voor Transit Oriented Development (TOD) aan de Zaancorridor.* BNA onderzoek ■ Triggianese, M., Cavallo, R., Baron, N, & Kuijper, J. (eds.) (2018). *Stations as nodes: exploring the role of stations in future metropolitan areas from a French and Dutch perspective.* TU Delft Open Books.



Milan: a design intervention aiming to rethink flows and public space, integrally redesigning infrastructure as a place for interaction: Under Current by Julia Zhu. (Zhu, 2025, Studio theme Milan East Ringroad Area, academic year 2024-2025, MSc2 Studio Architecture & Urban Design)



Systems Engineering

When designing large-scale technical system – as a complex of interdependent functions, components, and actions which serves a purpose – designers must take their time. Apart from technical complexity, organizational, social, and environmental aspects must also be addressed. How can we get grip on the development and realisation of such systems?

PURPOSE – "Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems over their life cycle" (Wikipedia, 2025). It has it origins in the US, in telecom, in aerospace and in the defence industry. Since the late nineties, systems engineering is commonly used in large infrastructure projects in the Netherlands (Figures 1 and 4).

Systems engineering is based on *systems thinking,* considering the world (or the Universe of Discourse) as a system or a set of systems. Another important principle is the *life cycle* approach: when developing a system, the whole life cycle should be considered.

APPROACH – Systems engineering distinguishes four basic steps and uses a number of principles, concepts, and methods. Often the v-model is used to describe its phasing, while its specific interpretation is defined by the engineering field and its application domain (Figure 2). In general, it comprises the following phases, once a client has decided to start a project.

1. *Definition*: this phase consists of the *identification* of the goal, objective, or mission of the system, followed by the *scope determination* which includes the system of interest, the environment, the system boundaries, and the external interfaces. The final step is the formulation of the *system requirements*, for which many guidelines can be formulated, similar to the SMART acronym (specific, measurable, acceptable, realistic, timely).
2. *Development:* the analysis of the system requirements leads to a functional decomposition of the system, while the design process elaborates on the technical elements and aspects. Design alternatives can be compared using a trade-off matrix (TOM) or a multi-criteria analysis (MCA). Characteristic for the v-model are the two important evaluation methods: *verification* and *validation*. The first means evaluating the design against system requirements: '*does it do it right*'. Validation means whether the design fulfils the user needs: '*does it do the right thing*'. This is an interlinked process depending on the number of design iterations.
3. *Realisation*: this phase incorporates the actual build, completion and processes which are needed, such as the communication of the project with the social environment and its daily functioning. In this phase verification and validation still play an important role.
4. *Operation & maintenance*: this phase is related to the life cycle of the system.

During the development process *interface management* can be done using methods such as the context diagram (Figure 5) and the N2-diagram. When systems engineering aims primarily for project

APPLICATION
Systems engineering has the most added value in large and complex projects with many participants and stakeholders in engineering domains such as civil infrastructure, aerospace, and software engineering. It is especially useful to verify and demonstrate expected performance to ensure that past design decisions are traceable.

LIMITATIONS
Systems engineering has less added value in the following cases: (a) small projects with only one designer and/or only one stakeholder; (b) projects where rationality is less important, such as art projects; (c) or when used for project control, because can lead to unwanted bureaucracy and rigid application.



Figure 1. HSL bridge across Hollands Diep, South Holland - North Brabant: the Dutch high-speed railway project was a pioneering project for the application of systems engineering in Dutch civil infrastructure. [© Rijkswaterstaat, Joop van Houdt]

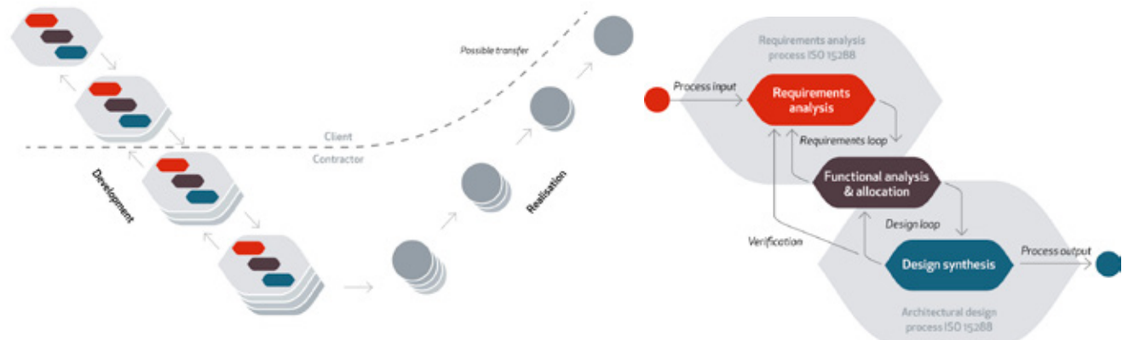


Figure 2. A v-model in the field of civil infrastructure: the client defines the system requirements during the definition step which form the starting point for the requirement analysis by the constructor as part of the development step. Successive steps are the functional analysis and allocation and design synthesis. These have an iterative character until the necessary level of detail is reached (right). After this, the realisation of the works starts until the moment of transfer to the client is agreed on (Alsem et al., 2013).

control, it can lead to unwanted bureaucracy. A related rigid, waterfall model-like way of application can limit its design iterations. An agile management approach, with methods like lean management, scrum and six sigma, offers more flexibility and interaction.

An advanced method for systems engineering is model-based systems engineering (MBSE). MBSE means that design data and information is primarily stored in (digital) models instead of documents. In this way systems engineering can be linked to technologies such as BIM, engineering databases, digital twins (Figure 3), and AI.

Sander van Nederveen, TU Delft

FURTHER READING ■ Alsem, D., Kamerman, J., Van Leeuwen, C., Van Ruijven, L., Den Toom, T., & Vos, M. (2013). *Guideline for Systems Engineering within the civil engineering sector. It's all about cohesion.* Version 3. Prorail, Rijkswaterstaat, Bouwend Nederland, Vereniging van Waterbouwers, NL ingenieurs, Uneto VNI ■ Centre for Digital Built Britain (CDBB). (2021). *Digital Twin Toolkit. Developing the business case for your digital twin.* University of Cambridge, Department for Business, Energy & Industrial Strategy ■ International Council on Systems Engineering (INCOSE). (2023). *Systems engineering handbook.* 5th edition. Wiley & Sons ■ International Organization for Standardization (ISO). (2023). *ISO/IEC/IEEE 15288. Systems and software engineering – System life cycle processes.* Edition 2. ISO ■ Wikipedia-contribuants. (2025, 15 August 2025). *V-model.* Wikipedia. https://nl.wikipedia.org/wiki/V-model ■ Wikipedia-contribuants. (2025, 14 May 2025). *Systems engineering.* Wikipedia. https://en.wikipedia.org/wiki/Systems_engineering.

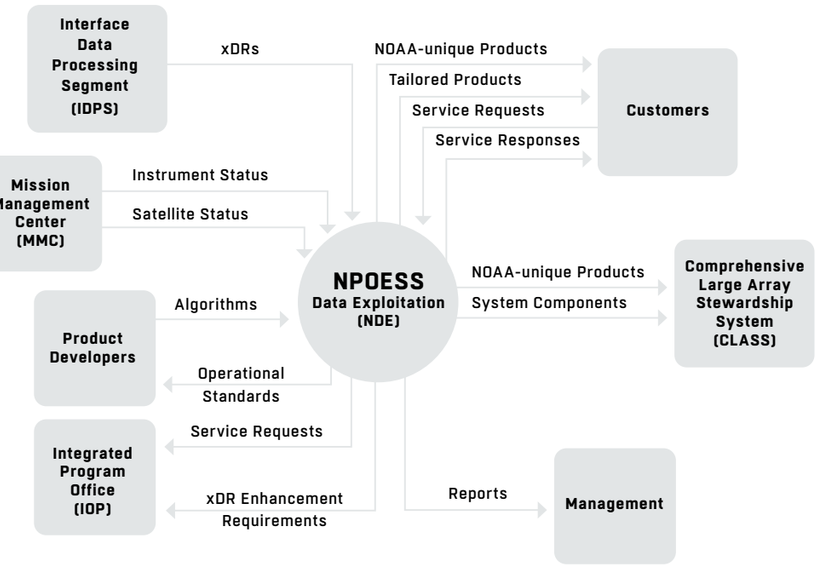


Figure 5. NPOESS Data Exploitation (NDE): central in this context diagram is the NDE system from the aerospace sector which manage observations of the Earth and atmosphere from satellites of the National Polar-Orbiting Operational Satellites System (NPOESS). It is part of the NPOESS program of NASA which coordinates the work of scientists, developers, and users of satellite data. The diagram shows its relationships and information flows between data providers, developers, customers, and its management. [PD NDE]

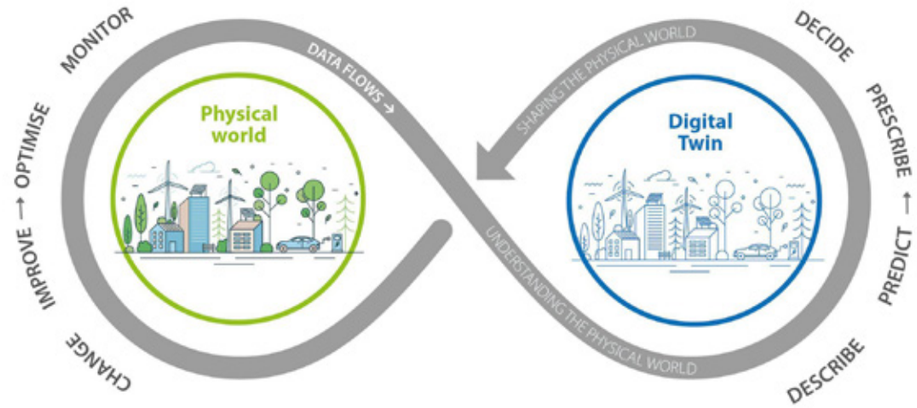


Figure 3. A digital twin represents the physical world based on instant data flows. Its main purpose is to support decision-making for potential interventions in the physical world based on simulation and prediction (Centre for Digital Built Britain, 2021). / **Figure 4. HSL tunnel in Rotterdam: another example of the application of systems engineering is the four kilometres long high-speed railway tunnel near Rotterdam-The Hague Airport (RTHA).** [© Rijkswaterstaat, Ton Poortvliet]



Train Station Design

The revisiting of station design in many cities marks a fresh look on its meaning and image against the idea that stations are places to avoid or to leave in hurry. There are few greenfield stations to design but a vast number of outdated stations and deprived surroundings. However, due to the static nature of the infrastructural basis and limited funding, it is often impossible to relocate the tracks or rebuild the station entirely. Are there opportunities to work around this with clever interventions which focus on access, attractiveness, and its surroundings? Can we improve stations without a complete overhaul and can we integrate other functions?

PURPOSE – For decades, station design was either grand or generic: cathedrals of movement or functional transit machines. Today, we are rediscovering the station as a hinge between systems and spaces – a place where regional fluxes and local life converge. Some of the most interesting station masterplans start with something modest: a new canopy, a better bus loop, more bike parking. But under the surface, these small interventions often carry larger questions – about urban form, social access, climate adaptation, and neighbourhood identity.

What follows is a method to design stations not as isolated objects, but as spatial catalysts, framed by five challenges as opportunities for integrated, iterative design. The idea is not to glorify infrastructure, but to show how good design – even in modest places – can help realign train stations with the city and its contemporary needs.

APPROACH – This design method is structured around five spatial interrelated lenses – each reflecting a recurring urban design challenge – and is illustrated with international best practices:

1. *Intermodality*: stations are increasingly complex interchanges between train, bus and tram, bike, foot, taxi, shared mobility, and car. In *Køge Nord (Denmark)*, a 225-meter pedestrian bridge seamlessly connects high-speed and local lines across a motorway, becoming both infrastructure, shelter, and landmark. In *Utrecht (the Netherlands)*, Europe's largest bicycle parking under a new elevated square anchors a massive modal shift. Meanwhile, in *Le Mans (France)* a glass canopy integrates a landmark station with a new light rail stop, bus platform, underground bike and car parking, with connections to a new hotel and conference centre. These examples show how well-designed infrastructure can stimulate the use of sustainable transportation, making intermodality invisible yet intuitive.

APPLICATION
This method is especially effective where infrastructure and place are not yet reconciled: (a) station (re-) development; (b) integration of mobility and urban regeneration goals; (c) modal shift ambitions with spatial quality requirements and (d) contexts where civic, infrastructural, and ecological needs intersect.

LIMITATIONS
Design sets the vision, but implementation relies on robust governance, aligned interests, and financial and technical realism. However, it often runs into structural obstacles:

- **Fragmented ownership: station areas are typically split between public and private, national as well as local land, complicating coherent development without active land policy.**
- **Lack of governance: the absence of strong public leadership or a resolute project manager leads to delays, diluted ambitions, or stalled coordination.**
- **Complex stakeholder landscape: with many actors involved – from municipalities and grassroot movements to national and regional transport agencies – collaboration requires structured governance models to avoid deadlock.**
- **Weak financing and phasing: without clear funding strategies, phased delivery, or land value capture, projects risk long delays or reduced scope.**



Top: Urban integration: railway station Driebergen-Zeist by Arcadis Landscape architecture & Urbanism. [©Arcadis]
Bottom: Intermodality: Gare du Mans in Le Mans. [CC IngolfBNL]

2. *Urban integration*: railway tracks often slice through cities, with their embankments creating socio-spatial ruptures. In *Driebergen-Zeist (the Netherlands)*, public passages grant pedestrians and cyclists easy access under the train tracks and to a bicycle parking and a 'living room' where passengers can wait for the train in comfort. In *Aarschot (Belgium)* a pedestrian and bicycle bridge hovers over the train tracks and gives access directly to the platforms, but also hosts bicycle parking. In *Alboraya (Spain)*, moving the train tracks underground gives space to a new urban park, with the old train station serving as neighbourhood café.
3. *(Re)programming*: transit-oriented development (TOD) around stations consists typically of dense and generic office and apartment developments. However, best practices demand tailored, community-based programming. In *Aarhus (Denmark),* the Dokk1 library merges civic services and light rail station access, becoming a true public condenser. In *Sint-Truiden (Belgium)*, a former industrial site now hosts a school, youth centre, and health campus. Meanwhile, *Onagawa Station (Japan)* by Shigeru Ban functions not only as a transit hub, but also as a bathhouse, retail centre, and scenic lookout – blending destination with daily life. The challenge is not scale, but to see how train station development can contribute to neighbourhood's needs.
4. *Public landscape*: station surroundings should not be residual zones but inclusive civic landscapes. In *Leuven (Belgium),* the Bellevue linear park replaces former sidings, introducing public greenery, an acoustic buffer, and a regional bicycle path in the neighbourhood. In *Jiaxing (China)* the new station square integrates a 1930s station replica above ground, while the tracks have been moved underground and the site has been transformed into a tree-filled park, merging memory, mobility, and public life in one continuous landscape. In the TGV station of *Avignon (France),* the infrastructure design integrates a reinterpreted agrarian landscape of plane trees, cypresses, and hedge lines within a linear public space that bridges historic land patterns and contemporary mobility. Here, design elevates logistics into place-making.
5. *Typological transformation*: the typology of the station is evolving. From monumental halls to hybrid kiosks or open pavilions, the station must resonate with its urban context. At *Zürich Hardbrücke (Switzerland)*, the station is conceived as an elevated urban balcony – a minimal yet powerful structure that blends seamlessly with the city's viaduct, proving that typological innovation can emerge from infrastructural clarity rather than architectural spectacle. *Herstal (Belgium)* blends the station entrance with a modest landmark building, a new public square and sculpted railway embankments. In *Barneveld Noord (the Netherlands)*, a temporary 'container station' becomes both identity and interface. These examples demonstrate how architectural ambition does not rely on scale.

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FURTHER READING ■ Guichot, F., & Van Acker, M. (2024). Learning from rural-urban stations: Strategies for rail-based development in a low-density Flemish landscape. *Journal of Landscape Architecture, 19*(2), 68-83 ■ Van Acker, M., & Triggianese, M. (2020). The spatial impact of train stations on small and medium-sized European cities and their contemporary urban design challenges. *Journal of Urban Design, 26* (1), 38–58. (2022). *Big plans for small stations.* UPA/ASP.







Top: (Re)programming: Dokk1, a multifunctional building at former industrial cargo docks in Aarhus by Schmidt Hammer Lassen (SHL). [© Adam Mørk] **/ Middle: Public landscape: Gare d'Avignon TGV by Jean-Marie Duthilleul, AREP.** [CC Jean-Marc Rosier] **/ Bottom: Typological transformation: Bahnhof Zürich Hardbrücke.** [CC Meekjt / © Roger Frei]





Urban Pathway Design

Many cities have developed large and intrusive infrastructures over time, which have often marginalised pedestrians who must walk in their shadows. How to open up neglected spaces and transform residual space into a pedestrian-accessible experience and in walkways that connect surrounding areas and create synergetic qualities?

PURPOSE – Urban development often celebrates the grand gesture: the highway project, the landmark station, the sculptural building. But the real coherence of a city lies elsewhere: in the spaces between. The narrow underpass, the shortcut, the staircase between two streets – these are the moments that quietly shape the urban experience. Pedestrians take them for their efficiency, but remember them for the way they frame movement, compress space, or reveal a city's hidden logic.

In a more human-centred approach to the city, such pathways can be transformed into intentional spaces, carefully designed to bridge the ruptures created by roads, rails, or canals. The result can be inviting: well-lit tunnels, lively viaducts, and pedestrian bridges, which prioritise both functionality and dignity. Well-designed pathways do more than connect two points: they stitch, invite, and mark. This contribution proposes a method to reclaim residual spaces, which are underused, neglected, or ambiguous urban areas, not as leftover space, but as potential pathways in their own right – capable of linking infrastructure and surrounding areas, reinforcing their identities, and enriching the everyday experience of the city.

APPROACH – Designing a pathway involves engaging with three interconnected aspects.

1. *Link – Pathways as connectors*: at their most basic, they solve discontinuities across roads, railways, canals, or topography. From pedestrian bridges in *Copenhagen (Denmark)* to the funiculars of *Medellín (Colombia)*, these infrastructures restore continuity where the city is broken. But beyond speed or directness, the best links also frame arrival, enhance safety, and connect multiple systems and modes. The 'Luchtsingel' in *Rotterdam (the Netherlands)* shows how even a temporary crowdfunded link can generate new networks between districts.
2. *Place – Pathways as meeting space*: some pathways do more than connect destinations – they become destinations. In *Kingston upon Hull (England)*, the Scale Lane Bridge does not just cross the river; it invites people to linger, sit, even ride along as it opens. In *Zaandam (the Netherlands)* the 'A8erna' transforms the space under a highway into a vivid urban

APPLICATION
Wherever pedestrian movement and spatial experience converge, the approach offers design agency for a range of urban conditions:

- **repairing broken urban fabrics (e.g. bridging railways, motorways, rivers);**
- **reconnecting informal or isolated neighbourhoods;**
- **supporting modal shifts and multimodal nodes;**
- **activating underused infrastructure (e.g. viaducts, tunnels, stairways) and residual spaces;**
- **creating spatial continuity in complex topographies or dense cores.**

LIMITATIONS
Despite their scale, pathways are rarely simple to design. Without coordination and ambition, they risk being reduced to a technical fix. Limitations include:

- **Fragmented ownership: often pathways run under or between properties with unclear legal status.**
- **Low political priority: small-scale, high-impact projects often fall between the cracks of mobility and public space policy.**
- **Security and perception: without active use, good design or proper maintenance, pathways can quickly become perceived as unsafe or unpleasant.**
- **Lack of governance: making a pathway requires not just a design but a process, involving transport agencies, landowners, and local users.**





Link: the 'Luchtsingel' in Rotterdam by ZUS Zones Urbaines Sensibles. [© Ossip van Duivenbode]



room for skating, playing, and pausing. And in *Singapore*, the sinuous Henderson Waves Bridge creates a suspended promenade that blends structural daring with tactile intimacy – a pathway that doubles as a park. These are not just links; they are urban stages.

3. *Transition – Pathways as thresholds*: some pathways do not just lead us somewhere – they can change entire neighbourhoods and even ourselves as persons. In *New York (United States)*, the High Line transformed an abandoned railway into a linear park, but its real impact was spatial and cultural: by turning a relic of industry into a suspended promenade, it catalysed the renewal of the Meatpacking District and redefined how we inhabit infrastructure. It is not just a route, but a repurpose of urban heritage, while sustaining part of the city's memory. In *Seoul (South Korea)*, the reclamation of the Cheonggyecheon River beneath a dismantled highway creates a slow descent from asphalt to water – a sensory shift from noise to calm and concrete to ecology. And in *Cergy-Pontoise (France)*, Dani Karavan's L' Axe Majeur stages a monumental walkthrough landscape and time. As one moves across ramps, terraces, and frames, the experience becomes more than physical – it becomes contemplative. These pathways do not just connect places; they induce personal transition. They make the city not only legible, but also emotionally legible.

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FURTHER READING ■ Smets, M., Van Acker, M., Orfeuil, J. P., Rebois, D., Amphoux, P., & Apel-Muller, M. (2018). *Passages-espaces de transition pour la ville/institut pour la ville en mouvement: Transitional spaces for the 21st-century city / Espaces de transition pour la ville du 21e siècle.* Actar D. ■ Ney, L., & Back, M. (2019). *Bridging: by foot and bicycle.* Ney & Partners ■ ZUS. (2016). *101 streets. The Implosion of the Public Domain.* ZUS.



Transition: L'Axe Majeur in Cergy-Pontoise (Val-d'Oise) by Dani Karavan. [CC Pline / CC Chabe01] **/ Place: the Lane Scale Bridge in Hull by McDowell+Benedetti, Matter Architecture.** [© Timothy Soar]



WHAT IS NEXT?

LOOK, THINK, AND ACT CONTEXTUALLY

When reflecting on the themes, case studies, and featured designs discussed in this design guide, the meaning and impact of infrastructure clearly appears to go beyond functionality and performance. The spatial and system integration of infrastructure is shown to have positive but also negative effects on society, the environment, and the economy. From a historical perspective, most Dutch infrastructure for urban and regional development had to be newly built in the post-World War II period, as a (re) construction task on all governmental levels. On top of this, the Netherlands had to respond to the 1953 flood disaster by building new flood defences.

The growing population and rising welfare led to suburbanisation, the growing need for mobility and related congestion and environmental pressure, like air pollution and degradation of the landscape. The government responded by regulations, norms, adaptation of infrastructure, and system optimisation. In the near and mid-term future, the maintenance and/or replacement of a vast amount of current infrastructure is necessary; this is a challenging task, which can lead to availability issues.

At the same time there is a high housing demand, society and the economy must keep going and the effects of climate change challenge the present system and planetary boundaries. Governments at various levels are responsible for infrastructure, yet they often lack sufficient budgets for asset management. The question then arises if successful planning and intervention approaches from the past can be applied in an uncertain future under new and ever-changing conditions, while the need for action is obvious.

GOAL-BOUND PARADIGM AND VALUE-BOUND PARADIGM

From a conceptual point of view, the postwar reconstruction period was dominated by a *goal-bound paradigm*, in which goals and means, efficiency, and blue-print planning for urban and infrastructure development were centrally led and developed (see table). The Oosterschelde-kering, part of the Delta Works, marked a new juncture since social protest in the 1970s put ecology and social involvement more prominently on the agenda. This led to the present advanced design beyond 'sober and efficient'. When looking at the featured designs and case studies in this guide, like the transformation of The Hague's city centre, the urban development of Spoorzone Delft, the reinforcement and renewal of the Afsluitdijk, and early stakeholder participation for the Blankenburgverbinding, another paradigm appears, reflecting other tangible and intangible values than strictly economic: the *value-bound paradigm*. This includes infrastructure interventions that not only focus on transport or flood protection but also consider various social and environmental values as a starting point to create significant benefits for the region, city, or landscape. Well-accessible, attractive urban and regional locations lead to higher land value and therefore to development prospects. Making better use of these mechanisms can redefine infrastructure as an investment tool, instead of only a financial burden. This creates value for the long term: a balance between city and landscape, accessibility and liveability, flood protection and freshwater availability, and in the end benefits society, economy, and ecology as a coherent whole.

Paradigms are conceptual frames of thought and action to coherently describe and explain a subject and its related practice, beliefs, attitude, body of knowledge, and working methods. The two previously distinguished paradigms are not normative moulds in which everything must fit; they are not 'good' or 'bad', or mutually exclusive. They emphasise a different context to start, focus, and act, but they share economic, environmental and sustainability aspects – as principles or boundary conditions – and several methods. Due to the problem situation and its contextual complexity, one may suit one particular project better than the other. The value-bound paradigm, including integrated approaches, fits better in a plan-like setting for system transition, while the goal-bound paradigm, including systems engineering, is more applicable if the purpose is fully clear, like technical replacement. However, in the latter case, we must also consider a number of different values as boundary condition. Both paradigms must deliver feasible prospects in a desired and likely future; both require appropriate modes of task engagement, expertise, and competences, within a more collaborative or competitive context. While the goal-bound paradigm is institutionalised in present practice and education, the value-bound paradigm still needs to be better defined, recognised, and established.

Governmental clients are key in this, since they define and put a problem situation on the political agenda. The involvement of other stakeholders, including citizens, in the early planning phase is not widespread in practice. Taking this route can lead to a different problem definition and solutions informed by a variety of values, which makes it possible to move beyond just solving a problem. This also applies to other client-contractor relationships. Collaboration between developers, designers, engineers, and other experts in the early planning stages can introduce the benefits of design and system thinking, in which stakeholders' viewpoints, aspired values, and interests can be translated into plausible solutions and positive effects. For education, it is necessary that students in an early stage engage in interdisciplinary collaboration and design within a transdisciplinary context. Research can contribute by providing more factual evidence for the paradigms and their constituent aspects, as context-related and valid representations of the present and future practice for infrastructure development and management.

Table. Contextual paradigms as conceptual representation of infrastructure development and management practices.

	GOAL-BOUND PARADIGM	VALUE-BOUND PARADIGM
Problem definition & Agenda setting	• problems are unambiguous and clear to define and delineate within a mono- or multidisciplinary and sectoral context • single-focus within a defined scope • economic and/or technical reasons are seen from a sectoral perspective	• problems are open, ambiguous, and vague, within an inter- or transdisciplinary and cross-sectoral context • multi-focus within a broad scope • social and/or environmental reasons are seen from a cross-sectoral perspective
Beliefs & Attitude	• economic growth for a prosperous society • sober and efficient design and realisation • single-purpose; a specific object for problem-solving codified in a fixed programme of requirements, fit for purpose • various values as boundary conditions • technology as enabler • decomposition of problem and solution in parts from an analytic perspective • a managerial and hierarchical approach, objective and result-oriented, with emphasis on time, costs, capacity, risks, and deliverables • dominant lenses: functionality, performance, complexity (technical, legislative)	• broad prosperity within planetary boundaries • sustainable social values within their economic, social, ecological, and cultural-historical context • multi-purpose; system level for problem identification within a multitude of contexts • various values as principles • infrastructure as a means to various ends • a developing and heterarchical approach; explorative, future-oriented problem-solving and value creation from a design thinking and system perspective • focus on purposes and processes with emphasis on social and/or environmental values, impact, and stakeholder commitment • dominant lenses: added value, collaboration, spatial quality, sustainability, adaptivity/resiliency
Knowledge & Competences	• information/data: sufficiently available or easy to gather to define problem, conditions, and effects • knowledge: vast and mature disciplinary knowledge, expertise, and experience • structure: sectoral, compartmentalised, and institutionalised knowledge and competence development by governments, companies, and knowledge institutes • education: formal and disciplinary in BSc major programmes, MSc programmes or tracks and graduation specialisms • research: thematic programmes within established disciplines and fields	• information/data: insufficiently available to define problem(s), conditions, and effects univocally • knowledge: not widely spread, immature inter- and transdisciplinary knowledge, expertise, and experience • structure: dispersed, fragmentised, and thematic coalition-based knowledge and competence development by governments, companies, and knowledge institutes • education: elective inter- and transdisciplinary education in various BSc en MSc programmes, courses, projects, and (graduate) studios • research: small-scale, dispersed, and individual PhD research
Methods, Techniques, Strategies	• e.g. social cost-benefit analysis, multi-criteria analysis, environmental impact analysis, systems engineering, asset management • project management focusing on project and outside communication • monofunctional design by (multi)disciplinary and sectoral collaboration	• e.g. research by design, integrated transition strategy, benefit-oriented design, integrated infrastructure design method, transit-oriented development, plan review, life cycle management • process management focusing on participation, cocreation, and interaction with stakeholders • integrated or multifunctional design by interdisciplinary and cross-sectoral collaboration
Perfor-mance practice	• public funding and public-private beneficiaries, making trade-offs/compensation, business case • construction- and cost-driven, transactional relationships, risk transfer	• public-private funding and public-private beneficiaries, making equal exchanges, add-on projects for added value and/or cost reduction, value- and business case • opportunity- and value-driven, collaborative partnerships, proportional risk distribution
Community	• sectoral and institutionally organised with a clear division of roles: client (governments), contractor (companies), knowledge institutes (universities, governmental institutes) • client and expert driven • promotion and communication by scientific journals and professional magazines	• loosely and temporarily organised within a network setting of initiators, designers, engineers, constructors, agents of governmental, knowledge institutes, platforms, and stakeholders, without a strict hierarchy between participants • initiator(s) and designer driven • promotion and communication by platforms and professional associations

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Backcover: Harderwijk, Gelderland: Aqueduct Veluwemeer crossing the N302 motorway. [© Sébastien Nagy]

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