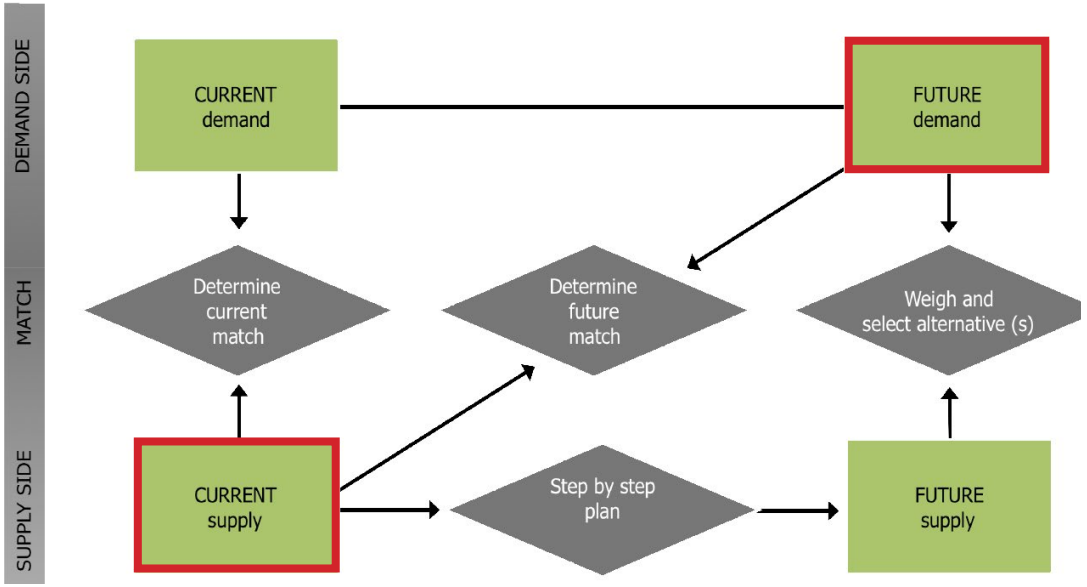
Economic feasibility of prefabricated solutions in healthcare design and construction industry.

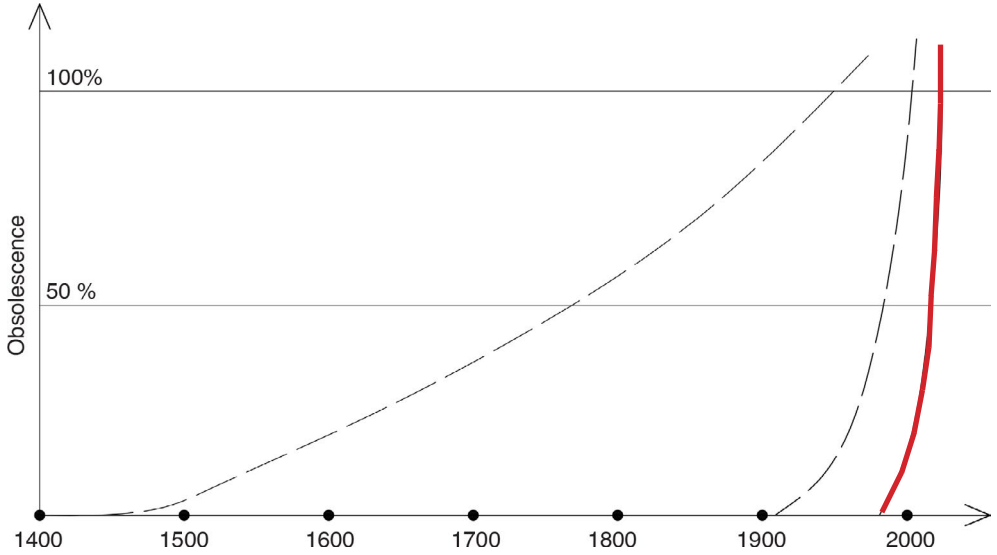
P5 presentation
Ivan Moiseenko
June, 26th, 2017

01. Problem analysis



(Source: De Jonge, 2016)

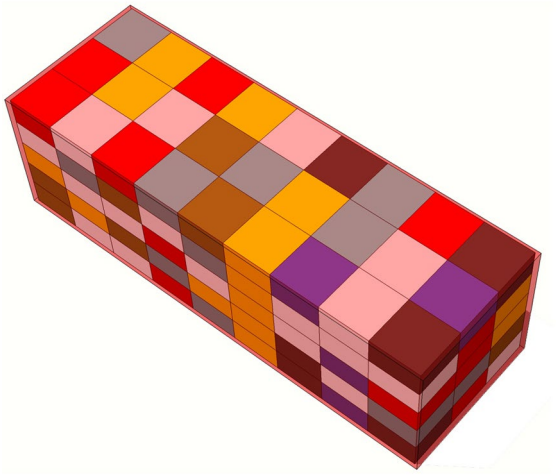
Current supply ≠ Future demand in modern hospitals



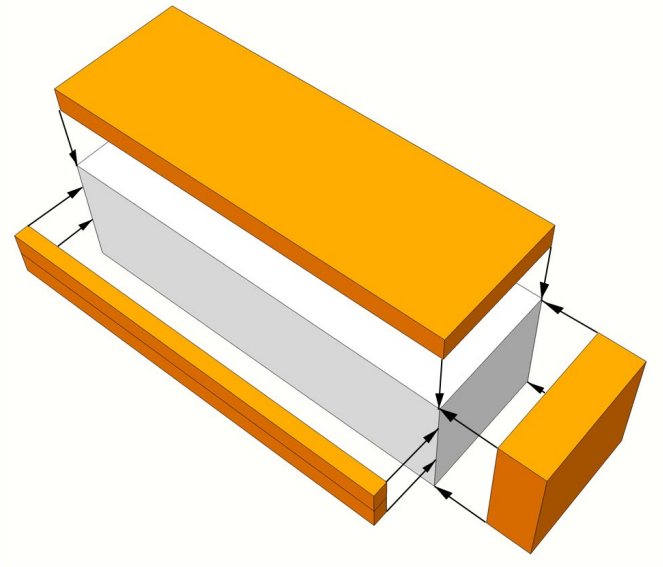
(Source: Capolongo et al, 2012)

Modern hospital obsolescence = 10 years

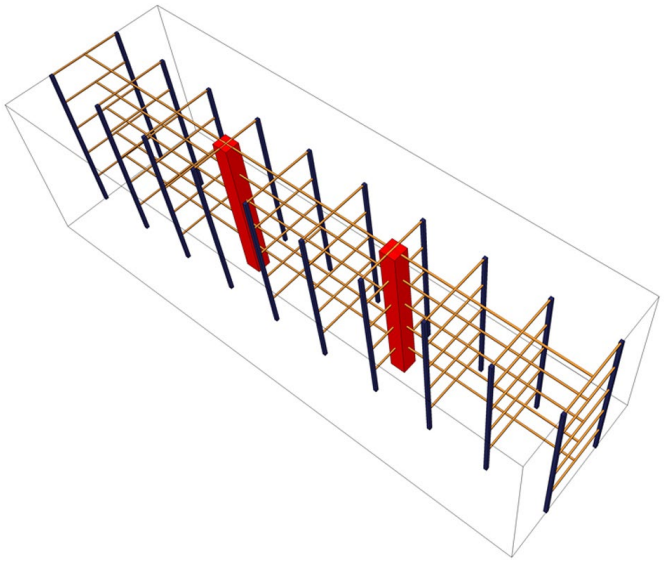
Flexibility as a strategy for unstable hospital environment



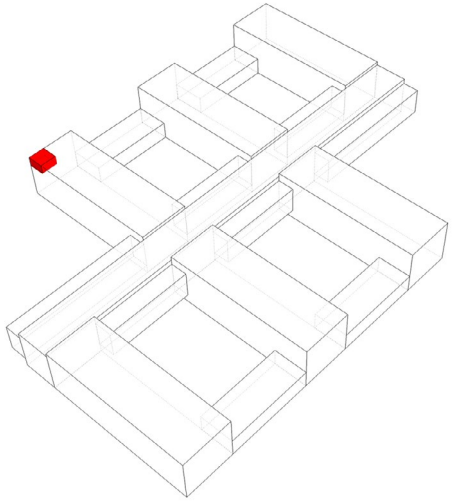
Constant surface flexibility



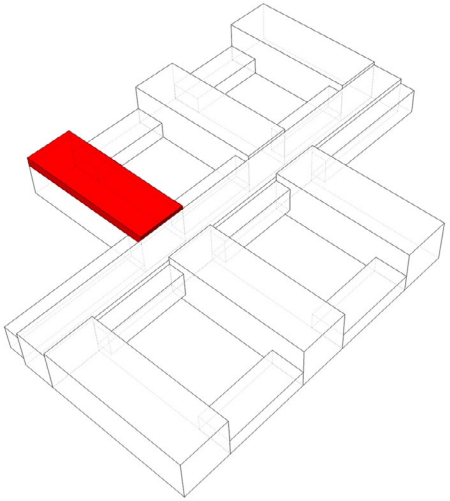
Variable surface flexibility



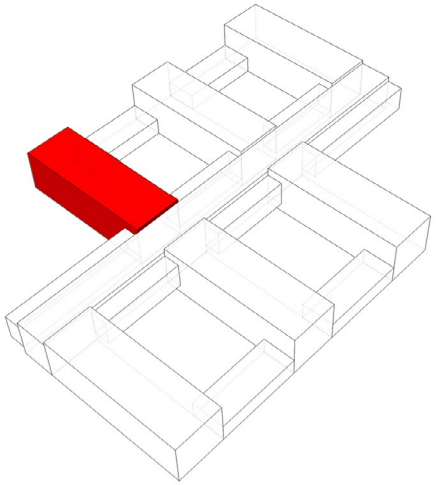
Operational flexibility



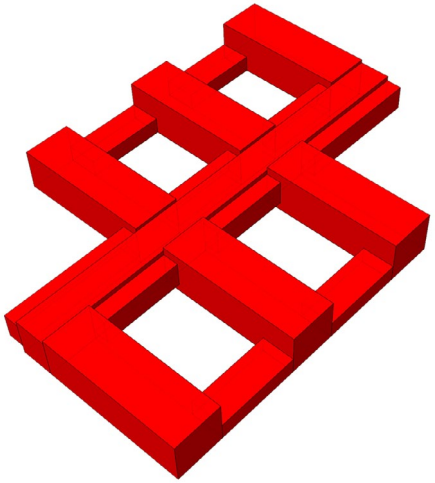
Individual room



Floor level

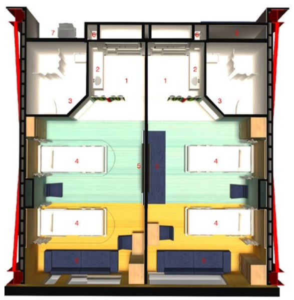


Bulding level

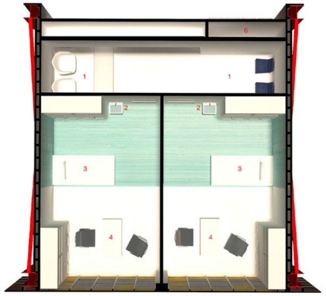


Hospital complex

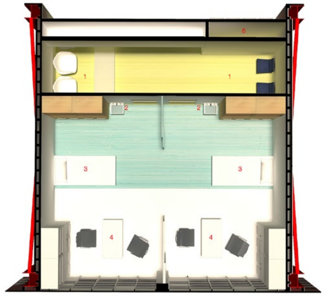
Individual room



2 double-patient wards

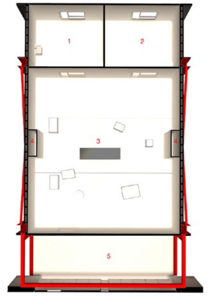


Practitioner office



Practitioner office with movable wall

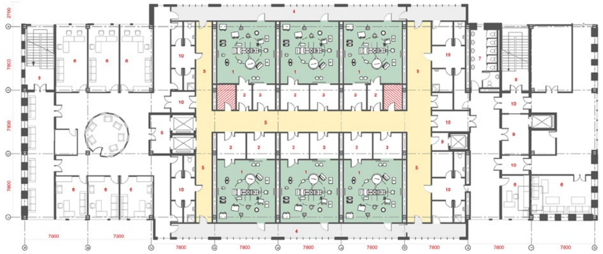
Intensive care unit



Surgery room

Functional floor

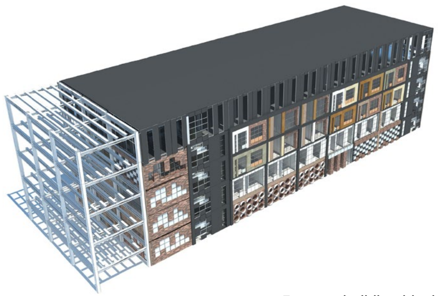
Ward floor



Surgery floor

Healthcare related facilities floor

Building level

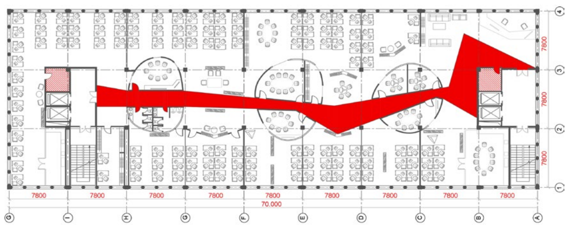


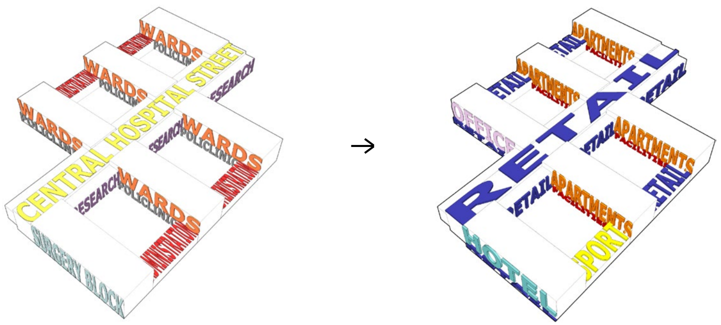
5-storey building block

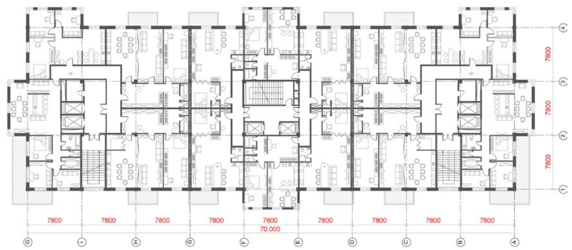
5-storey building block with hang cantilevered modules

7-storey building block with hang cantilevered modules

Hospital complex





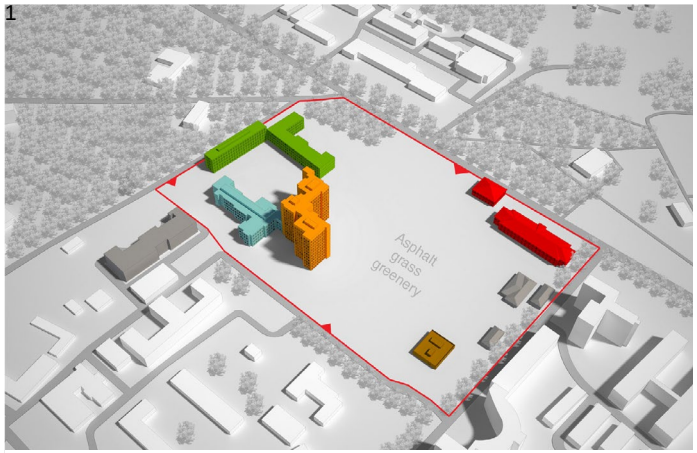


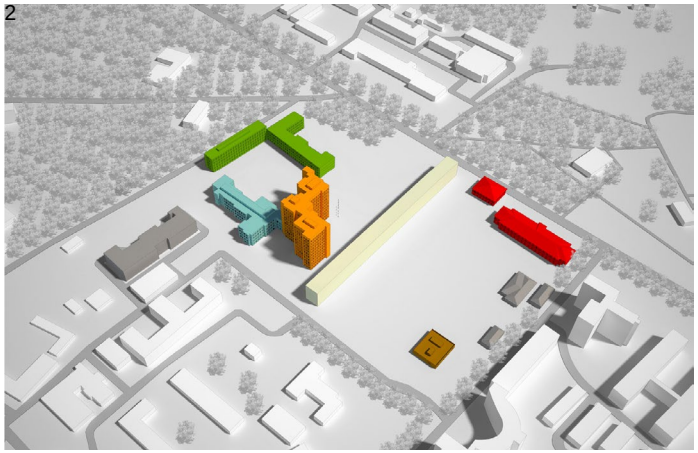
Conversion of hospital complex into multi-functional residential complex

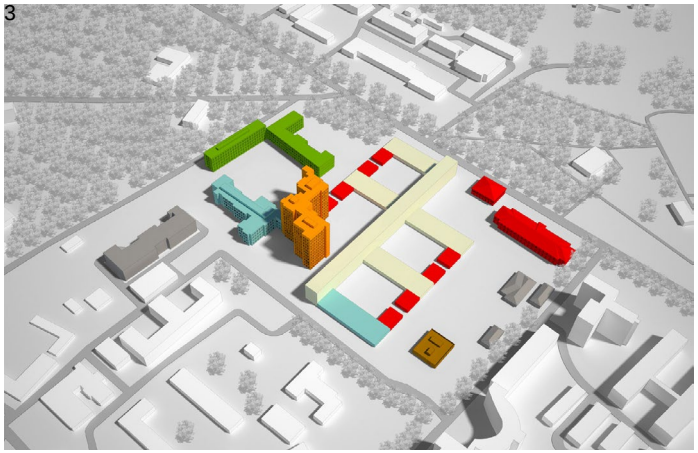
Modular construction as an answer to hospital flexibility

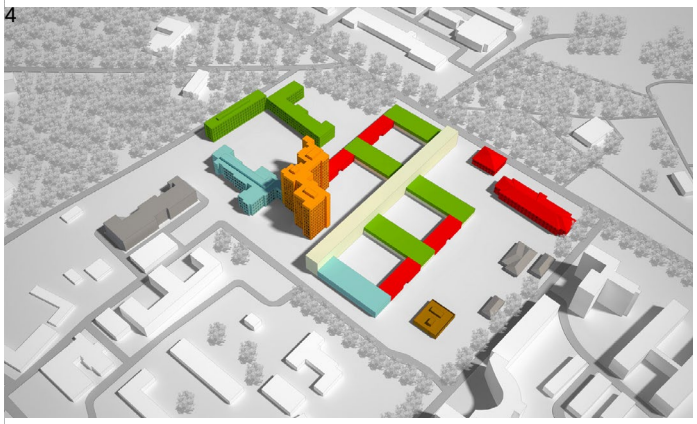
- High speed of construction, quick start of exploitation
- Quick respond to current hospital spatial needs
- Zero waste based on Lean management
- Factory installations of equipment
- Higher quality final product
- Maintain of the building during entire life cycle
- Reduction of on-site work
- Customizable layout

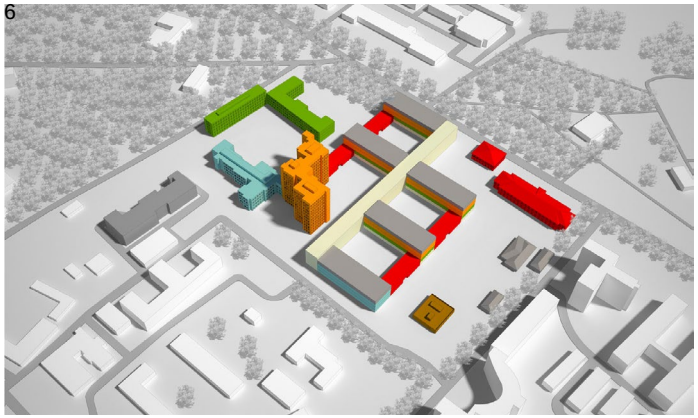
Cadolto modular hospital

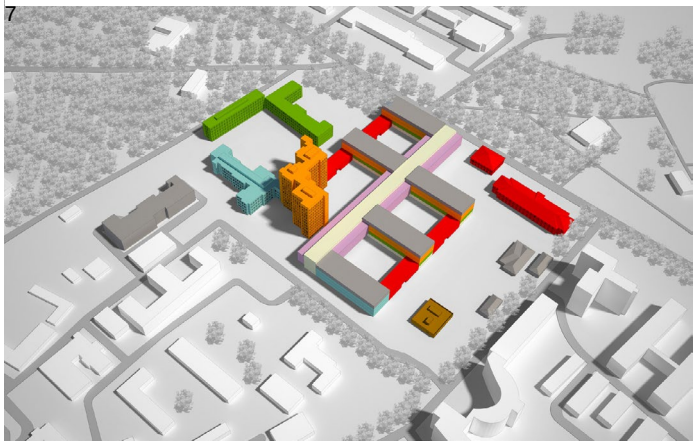


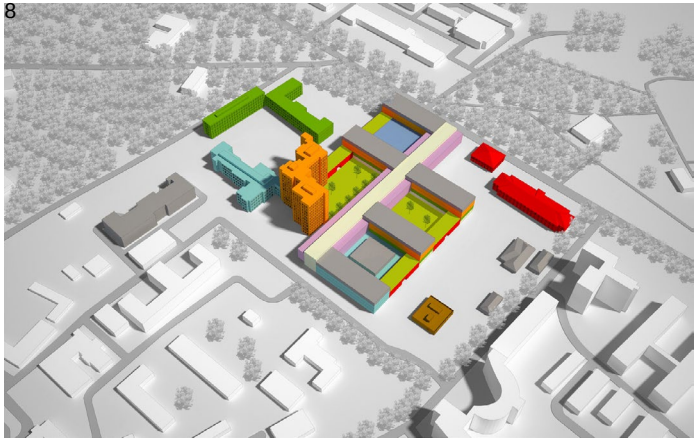


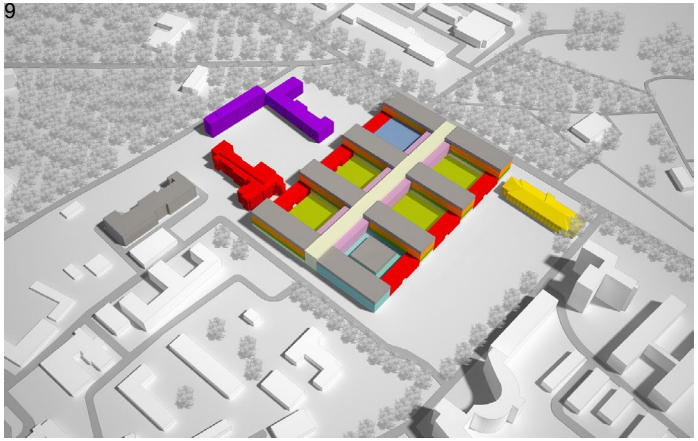












Healthcare related facilities
Administration
Policlinic
Wards
Research facilities
Surgery block
Nutrition unit
Technical facilities
Internal green yards
Visitors' hotel
Office

Feasibility study concept

Materials required	Materials costs	Legal requirements	Process structure	Schedule phases
Labor required	Labor costs	Legal obligations	Company's structure	Schedule deadlines
Resources required	Resources costs	Legal codes		
Transport required	Transport costs			
	Benefits > Costs			

Feasibility study:

The degree to which the economic advantages of something to be made, done, or achieved are greater than the economic costs

Feasibility study concept

Materials required

Labor required

Resources required

Transport required

Materials costs

Labor costs

Resources costs

Transport costs

Benefits > Costs

Legal requirements

Legal obligations

Legal codes

Process structure

Company's structure

Schedule phases

Schedule deadlines

The main goals of the research

Economic feasibility

Materials costs

Labor costs

Resources costs

Transport costs

Benefits > Costs

Operational feasibility

Process structure

Company's structure

- **Identify possible time savings in modular construction process**
- **Identify possible cost savings in modular construction process**

02. Research questions and research design

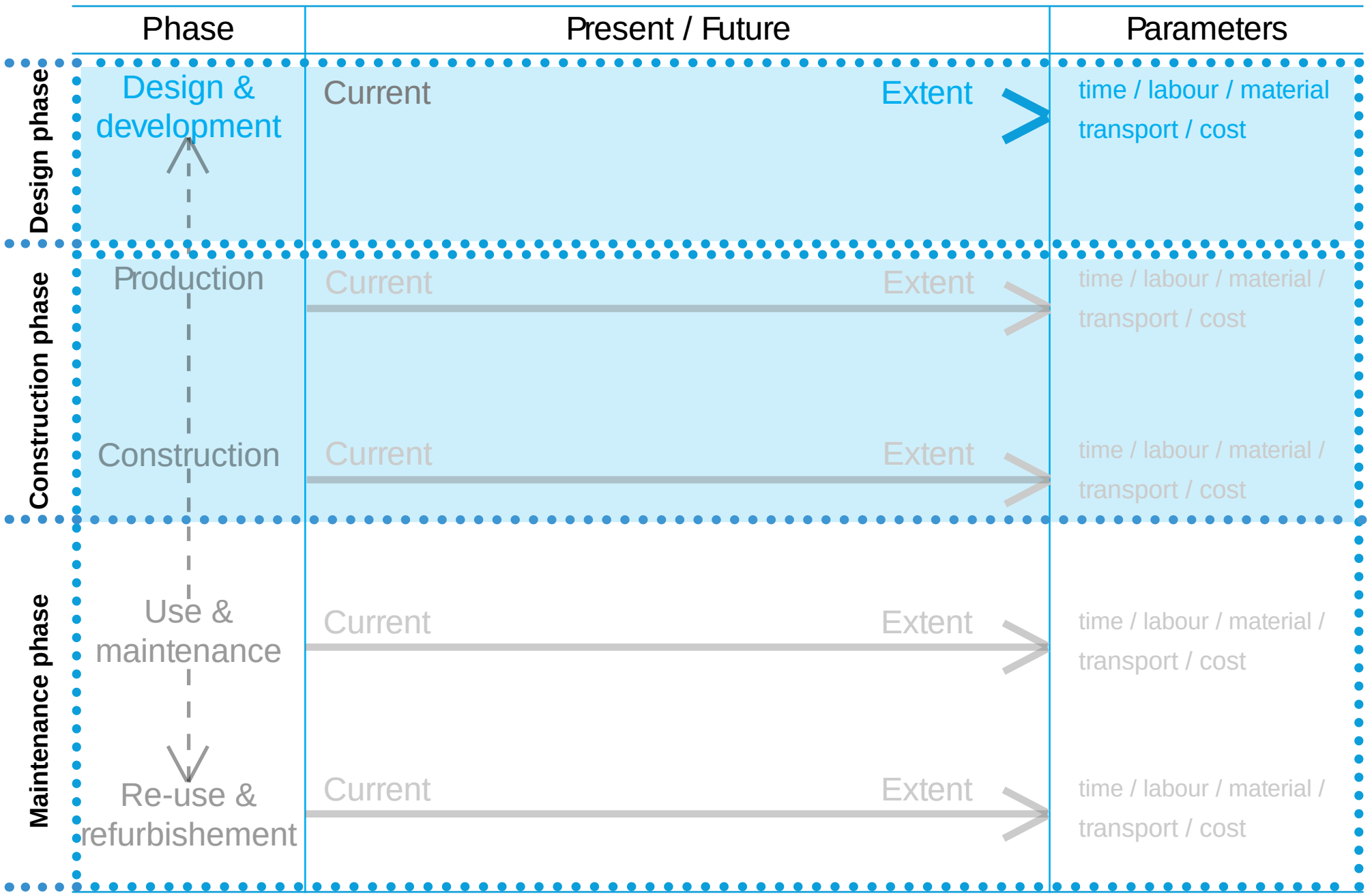
Main research question of the project:

To which extent are prefab solutions in healthcare design and construction processes are more economically feasible than traditional methods?

Sub-questions:

- **To what extent is prefab used in current situation in healthcare sector?**
- **To what extent is enlarging the amount of prefab elements feasible considering the design and construction process?**
- **Which parts of the healthcare facilities are mostly suitable for implementation prefab solutions in a cost-effective way?**

Conceptual model of the research



Phasing of the research

Theoretical part (P1 - P2)

Phase 1:

In-depth literature sutdy, analysis of modular construction process
(literature review, semi-structured interviews)

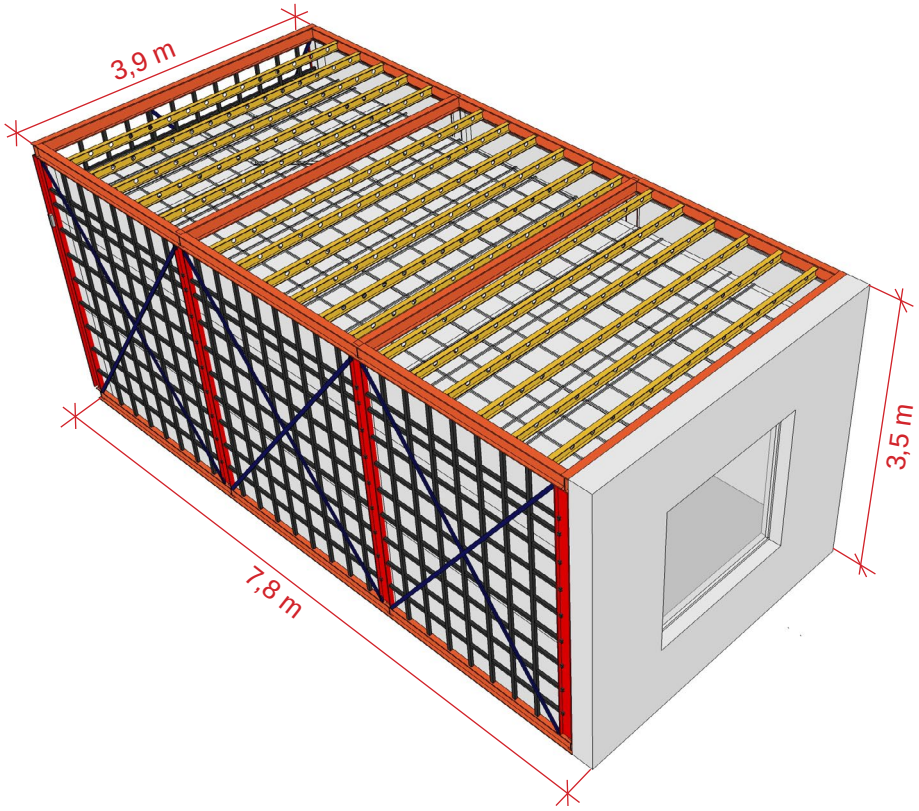
Empirical part (P3 - P4)

Phase2:

Assessment of time and cost savings in modular construction
in 3 main phases of hospital life cycle: design, construction and maintenance

Final product of the research

Summary of time and cost savings in modular construction as % from conventional building process



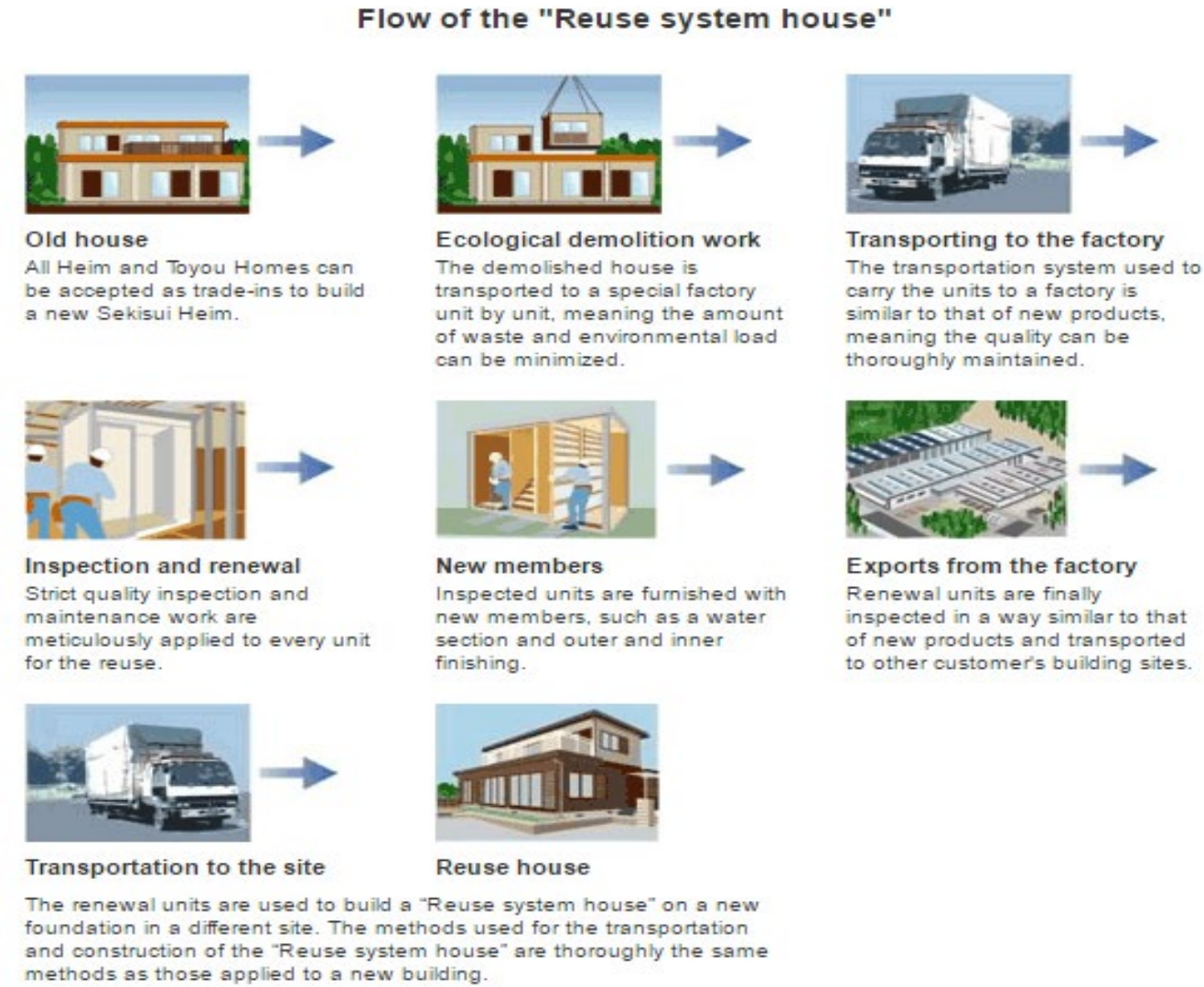
Standard module is taken for the analysis

Limitations of the research

- **Limited data regarding prices and costs of medical equipment**
- **Limited data regarding manufacturing process of the modules**
- **Costs of the number of parameters are educated guess**

03. Results of literature survey

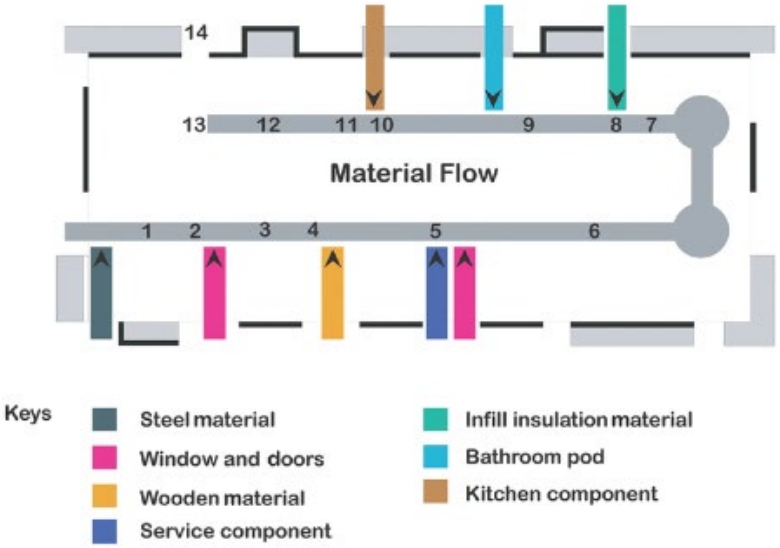
Lean management and circular economy are main components of modular production



(Source: www.sekisuiheim.com)

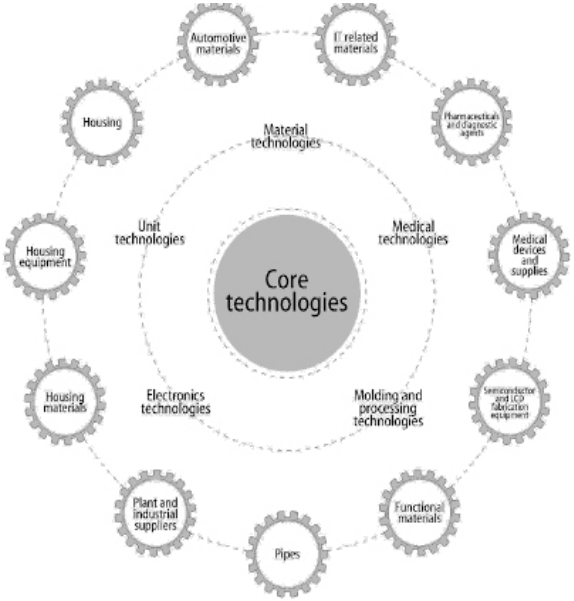
Sekisui Heim lean management system

Factory production chain in modular construction. Japan case study



Factory layout

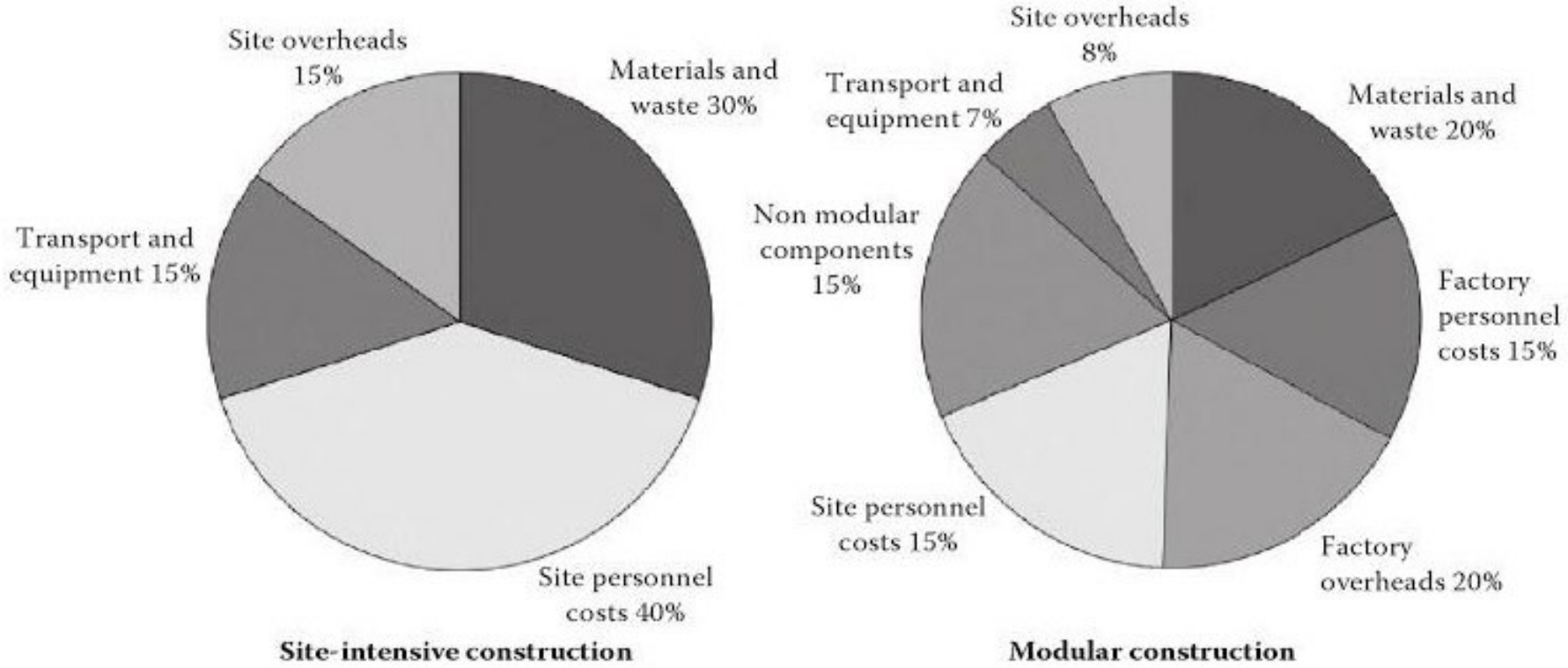
Linear assembly lines



Industry collaboration

Static assembly lines

Costs and time in modular construction



Benefit of modular construction	*Cost savings relative to site-intensive construction*
Site preliminaries	5–8%
Client's consultant fees	3–4%
Snagging reduction	1–2%
Financial savings due to speed of construction	2–5%
Total savings as proportion of the total building cost	11–19%

50 % time savings in modular construction

(Source: Lawson, M et al, Design in modular construction, 2014)

Risks in modular construction

Table 18.3 Summary of perceived risks for various forms of construction

Process stage	*Risk description*	*Brick and block*	*Open panel*	*Hybrid*	*Modular*
Planning	Unpredictable planning decisions			○	○
Preconstruction	Late appointment of supplier		○	●	●
Preconstruction	Lack of standardisation possible in the manufactured components		○	●	●
Detail design	Design changes after placement of order		○	●	●
Construction	Foundation inaccuracy affects installation		○	●	●
Construction	On-site components may be incompatible with manufactured components			○	●
Construction	Quality and accuracy problems	○			
Construction	Price fluctuations during construction	●			
Construction	Delays due to bad weather	●	○		
Construction	Lack of trade skills on site	●	○		
Construction	Service installation faults	●	○		
Construction	Health and safety hazards	●	○		
Occupation	Completed construction not to specification	●	○		
Occupation	Defects at handover or in liability period	●	○		

Source: National Audit Office, *Using Modern Methods of Construction to Build More Homes Quickly and Efficiently*, 2005.

Note: ● = high risk, ○ = medium risk.

(Source: Lawson, M et al, Design in modular construction, 2014)

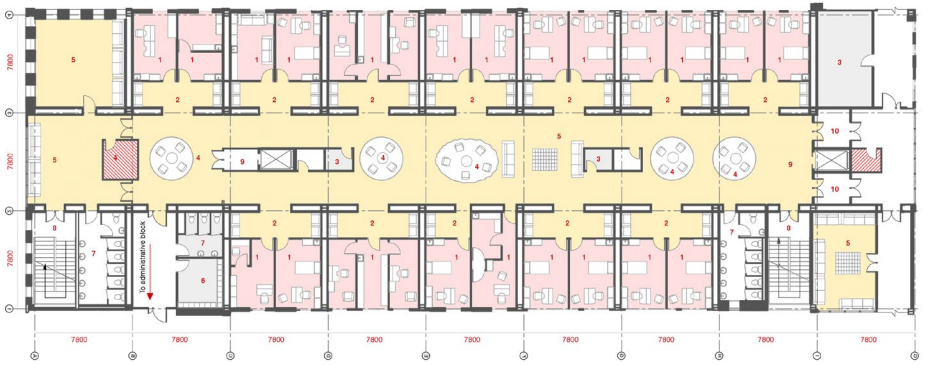
04. Design phase

Off-site or on-site?

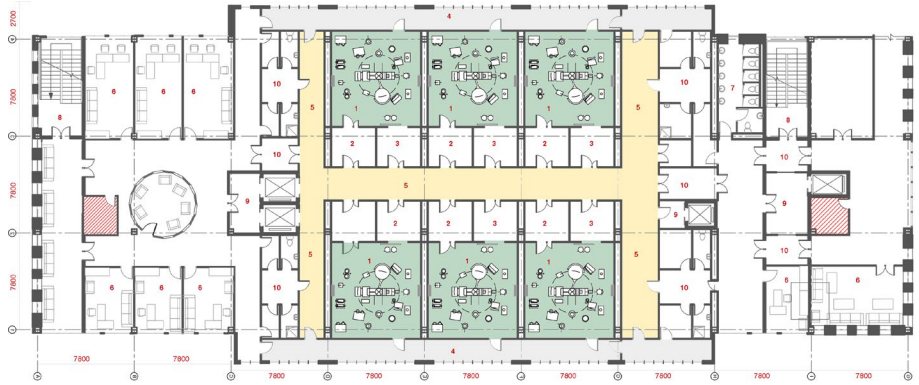
Parameter	4-sided modules	Partially open-sided modules	Open-sided modules
Flexibility (max united space)	3,9 x 16 m	3,9 x 16 m	12 x 12 m
Max length	16 m	16 m	12 m
Depth of main horizon. beams	150 - 200 mm	300 - 450 mm	300 - 450 mm
Depth of combined floor and ceiling	300 - 450 mm	300 - 450 mm	600 - 800 mm
Crossection of main columns	70 - 100 mm	70 - 100 mm	100 - 160 mm
Thikness of longitudial walls	65 - 100 mm	100 mm with additional bracing	100 mm with additional bracing
Max height of the building	2 - 25 floors (combined with concrete or steel core)	6 -10 floors	up to 10 floors
Max height of the module	3,6 m	3,5 m	3,5 m

Program of the hospital affects the choice

Ward floor



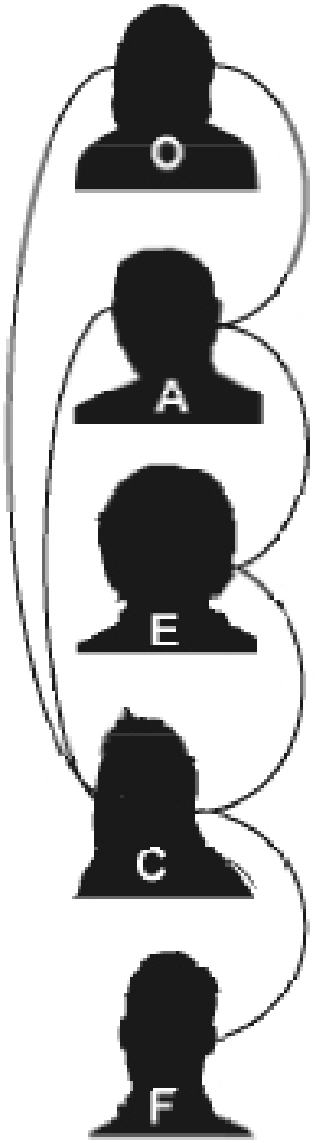
Policlinic floor

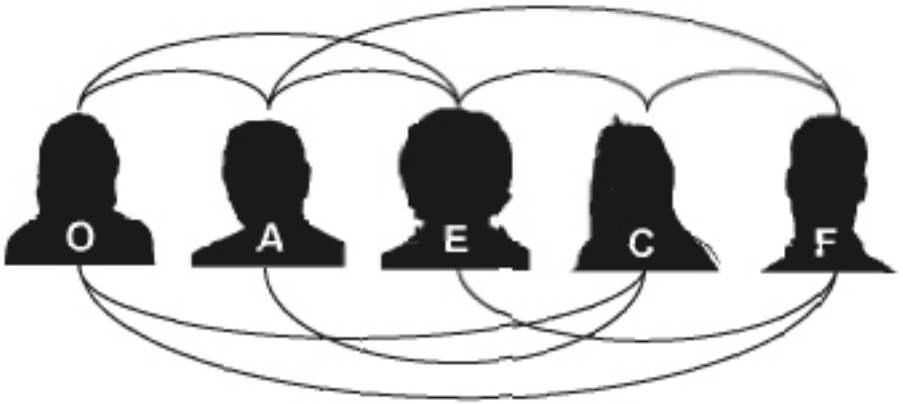


Surgery floor

Public / office floor

Procurement process. Vertical vs horizontal





O - owner

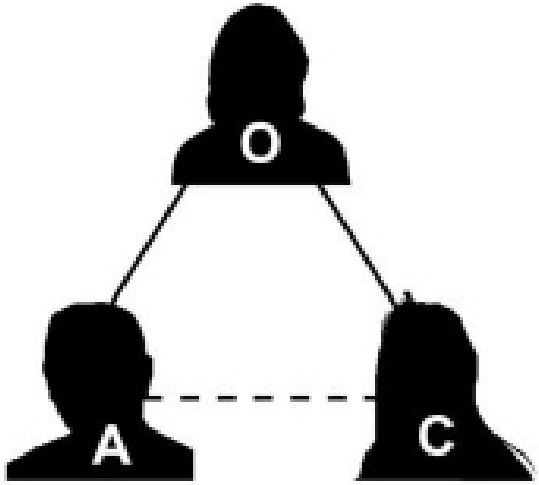
A - architect

C - contractor

E - engineer

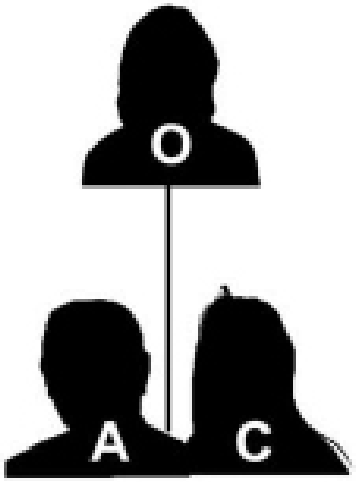
F - fabricant (manufacturer)

Procurement process. The earlier the better.



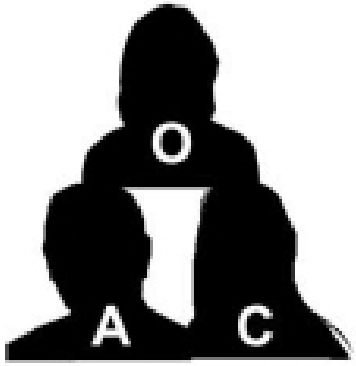
DBB

Design Bid Built



DB

Design Built



IPD

Integrative Project Delivery

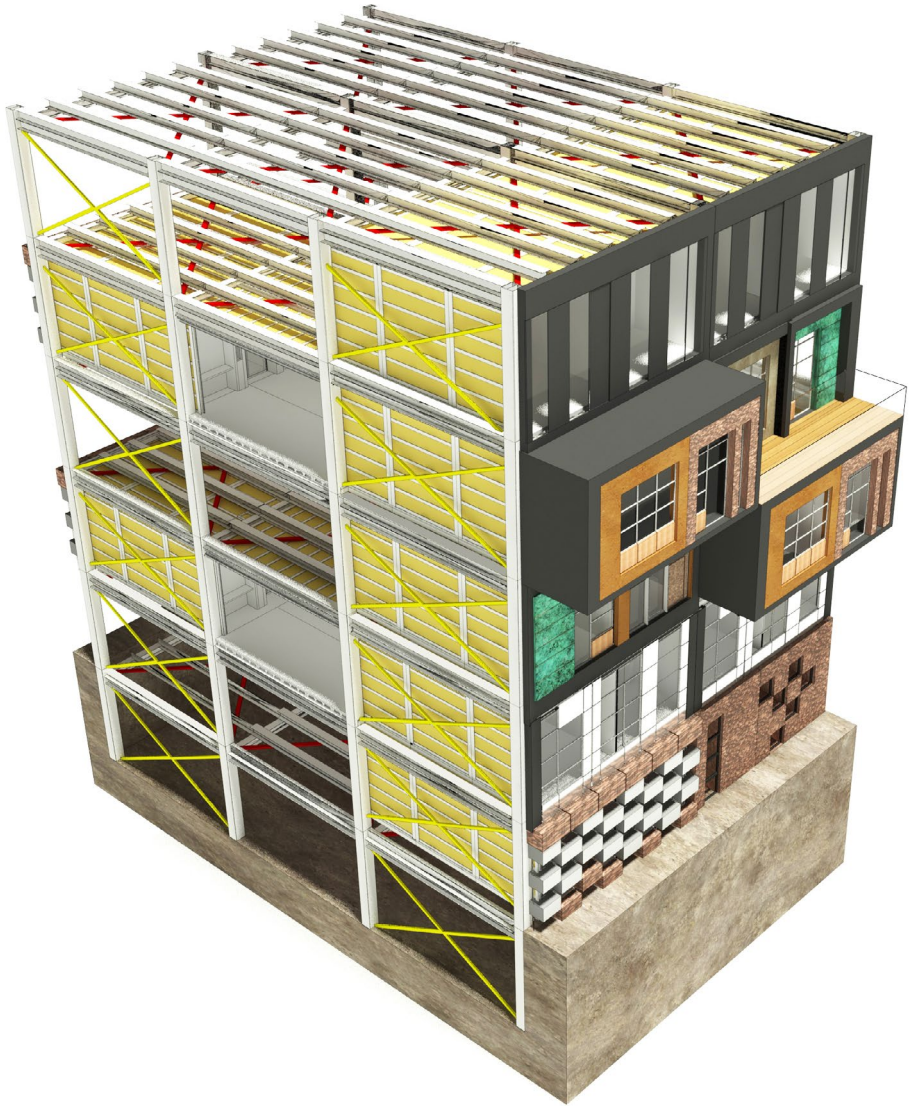
O - owner

A - architect

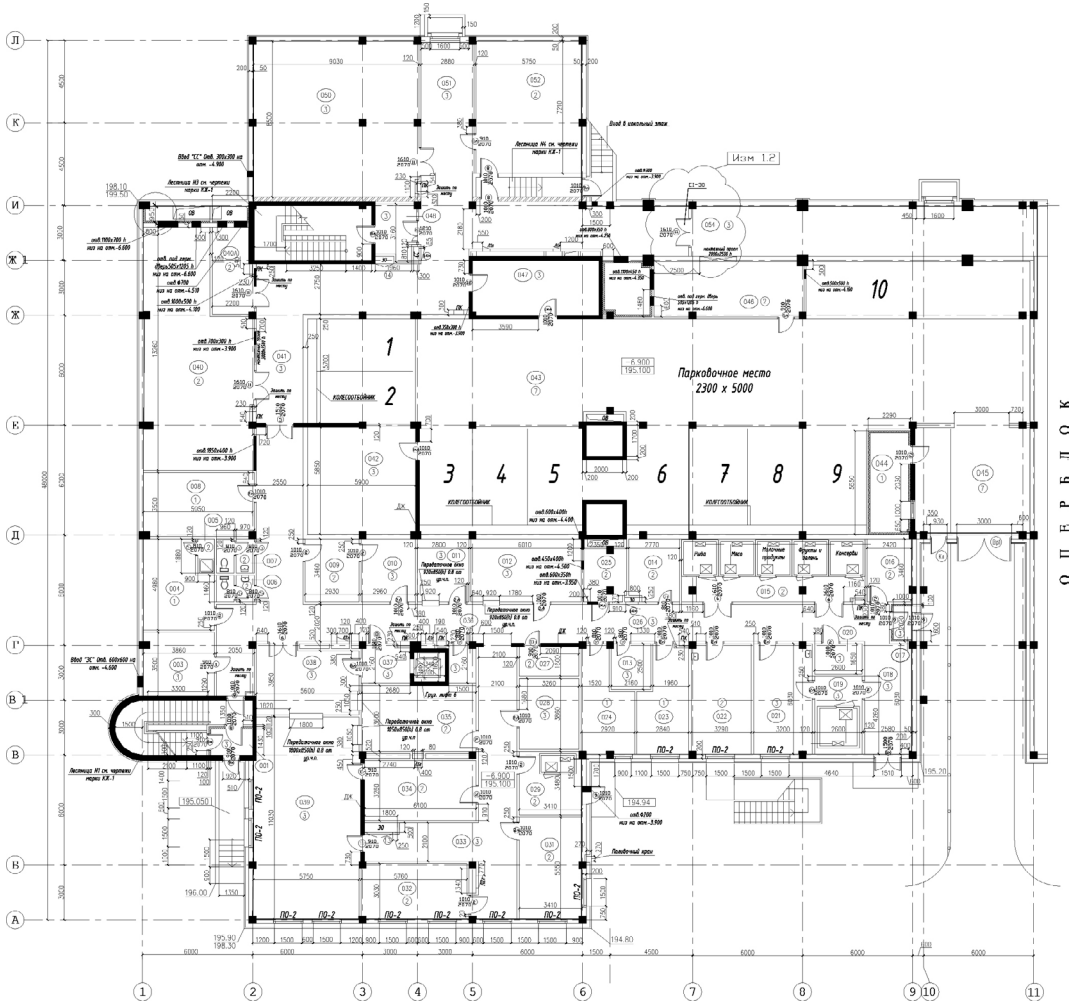
C - contractor

(Source: Prefab Architecture, Timberlake, J., 2010)

No design phase at all (?)



Modular design



Conventional design

Maasstad hospital, Wiegerinck architects, 2016

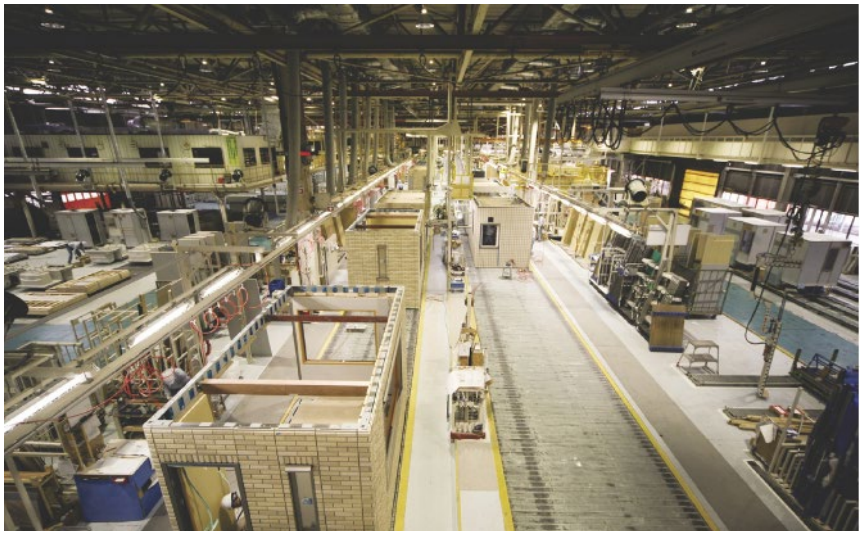
Design phase: 2012 - 2014 (2 years)

Alkmaar hospital extension, De Meeuw 2013

Design phase: 2013 (2 months)

(Source: De Meeuw & Wiegerinck architects interviews, 2017)

Factory organisation and investments



Linear,
Highly automated assembly line

- Fever design flexibility options
- Higher amortization and maintenance costs
- Lower availability of the space in factory floor based on organisation of production
- Higher production output of the factory
- Production time: 4-line factory: 3 modules / line / day = 12 modules / day
  3000 modules / year

Static,
Low automated assembly line

- Greater design flexibility options
- Lower amortization and maintenance costs
- Higher availability of the space in factory floor based on organisation of production
- Lower production output of the factory
- Production time: 3-7 days / 1module
  4 - 6 modules / day and 800-1200 modules / year

Factory initial investments

5 - 10 mln Euros

1 mln Euros

6 - 12 months

It results in additional 330 Euro / module in linear production and 900 Euro / module in static production

(Source: De Meeuw interview, 2017)

BIM as boost factor

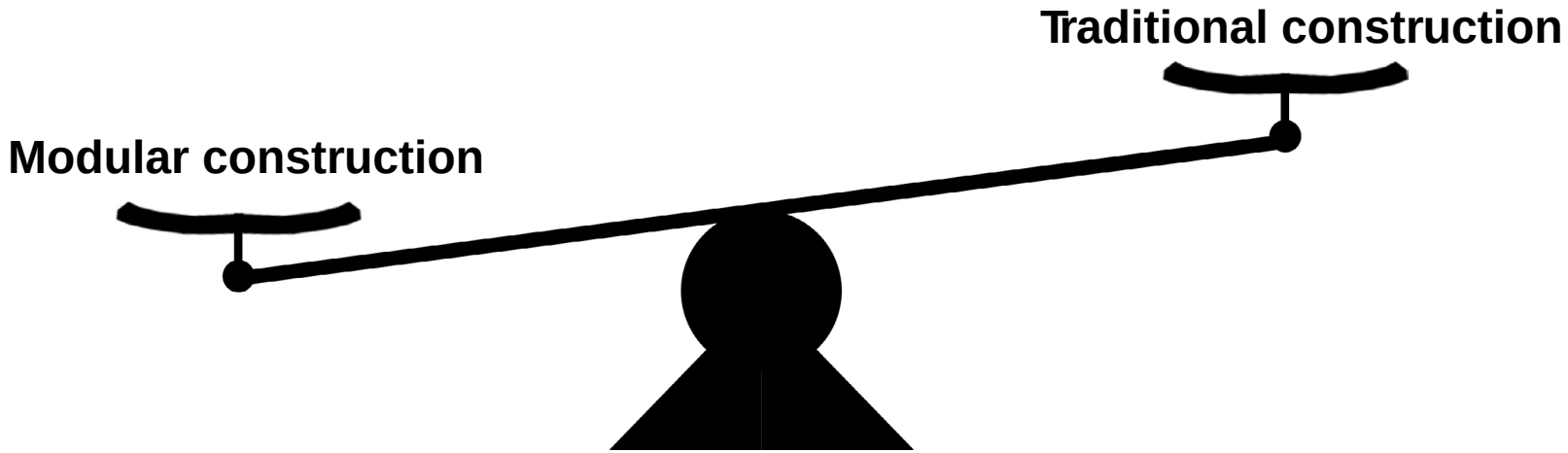
Traditional design

Modular design

(Source: Prefab Architecture guide, 2010)

Savings in design phase

Parameter	Modular coanstruction	Conventional construction	Savings, %
Time savings	0 - 15 % from conventional design	100 %	85 - 100 %
Cost savings	3 - 4 % from entire construction budget	6 - 8 % from entire construction budget	50 %



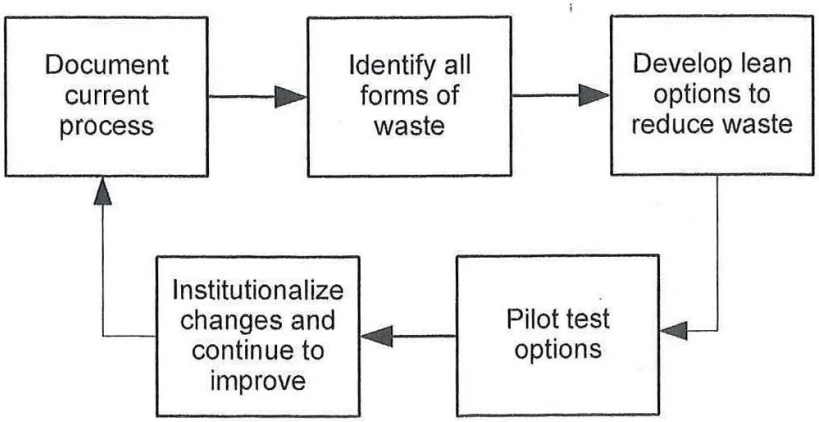
Data collection

- **Time savings:** De Meeuw interview
  Wiegerinck Architects interview
  Peter Luscuere (TU Delft)
  Literature review

- **Cost savings:** Literature review
  Wiegerinck Architects interview
  De Meeuw interview

05. Construction phase

Lean management

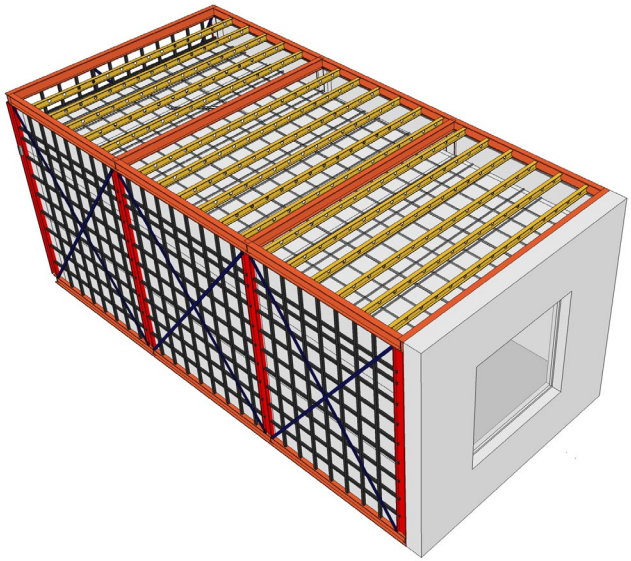


Parameter	Modular construction	Traditional construction
Amount of waste generated per 100 m2	**1,5 tons**	**4,5 tons**
Construction waste recycling efficiency	**70 - 85 %**	**30 %**

(Source: Lachimpadi S. K. at al, 2012. Construction wste minimisation comparing conventional and precast construction)

Materials and components. Getting data

Analyzed module



Amphia hospital, Breda, Wiegeinck Architects

- **Installation costs**
- **Construction elements costs**
- **Medical equipment costs**

Materials & components cost comparison

Element	Quantity	Weight of 1m length, kg	Price per m length	Total price, Euro	Total weight, kg	Manufacturer	Min price	Manufacturer (so	Most expected price	Manufacturer (sour	Max price	Manufacturer (source)
Main load-bearing skeleton												
Main column I-beams HEA 120 160x114 mm, red (N 12)	8 (length 3 m)	20,3 kg	1,36 Euro / kg	662,6 Euro	487.2 kg	Taken from bouwkosten.nl	10 Euro/m length = 240 Euro	Severstal (Russia)	17,5 Euro/m length (1,36 Euro/kg) = 420 Eur	bouwkosten.nl	27,6 Euro/m length = 662.6 Euro	bouwkosten.nl
Main horizontal I-beams HEA 160, 160x152 mm,orange (N 16	4 (length 7,6 m)	31 kg	1,35 Euro / kg	1.272 Euro	942 kg	Taken from bouwkosten.nl	10 Euro/m length = 304Euro	Severstal (Russia)	27,5 Euro/m length (1,36 Euro/kg) = 836 Eur	bouwkosten.nl	1,35 Euro/kg x 30,4 m x 31= 1272 Euro	bouwkosten.nl
Main horizontal I-beams HEA 160, 160x152 mm,orange (N 16	8 (length 3,7 m)	31 kg	1,35 Euro / kg	1.238,7 Euro	917.6 kg	Taken from bouwkosten.nl	10 Euro/m length = 296 Euro	Severstal (Russia)	17,5 Euro/m length = 518 Euro	bouwkosten.nl	27,6 Euro/m length = 817 Euro	bouwkosten.nl
Secondary I-beams, HEA 100, 100x96 mm yellow (N 10)	34 (length 3,7 m)	20,8 kg	1,35 Euro / kg	3.532 Euro	2138 kg	Taken from bouwkosten.nl	7,8 Euro/m length = 981Euro	Severstal (Russia)	14 Euro/m length = 1761 Euro	bouwkosten.nl	1,35 Euro/kg x 2.616 kg = 3.532 Euro	bouwkosten.nl
Diagonal stiffness connections	6 pieces	1,1 kg	1,36 Euro / kg	25,6 Euro	18.84 kg	Taken from bouwkosten.nl	1,2 Euro/m length = 57,6 Euro	Severstal (Russia)	6 Euro/m length = 144 Euro	bouwkosten.nl	15 Euro/m length = 720 Euro	bouwkosten.nl
Tertiary sheathing (quadrant rods 30 x 30 mm)	114 rods	1,39 kg / 1m length	1,36 Euro / kg	756 Euro	556 kg	Taken from bouwkosten.nl	1,2 Euro/m length = 479 Euro	Severstal (Russia)	114 x 3,5m x 1,39 kg x 1,35 Euro/kg = 756 Eur	bouwkosten.nl	3,8 Euro/m length = 1516 Euro	bouwkosten.nl
Walls												
Gipsum-fiber board (2500x1200x12,5 mm)	56 sheets	31,5 kg / board	45,15 Euro / board	2520 Euro	1764 kg	Knauf, taken from bouwkosten	31,5 Euro/board x 56 = 1764 Euro	Knauf (Russia)	37,3 Euro/board x 56 boards = 2089 Euro	snabmsk.ru	45,15 Euro/board x 56 = 2.528 Euro	bouwkosten.nl
Wall finishing layer (anti-bacterial paint)	65 m2 = 10,8 liters	0,166 liter/m2	24 Euro/1 liter	1800 Euro		Taken from bouwkosten.nl	19,2 Euro/Liter x 10,8 L x 2 =415 Euro	bouwkosten.nl	27,8 Euro/Liter x 10,8 L x 2 layers = 600,5 Eu	bouwkosten.nl	34,2 Euro/Liter x 10,8 Euro x 2 = 738,7 Euro	bouwkosten.nl
Ward door	1			588 Euro	35 kg		467 Euro/door	spi-polymer.ru	587 Euro/door	bs.stroynet.ru	588 Euro/door	
Insulation layer (6.000x600 mm, thikness 80 mm)	1, 96 m3 per module	52 m2 per module is required	6,95 Euro / m2	360 Euro	77 kg	Rockwool, 6000x600x50 mm, NL	6.95 Euro/m2 x 52 m2 = 361,4 Euro	bouwkosten.nl	8,4 Euro/m2 x 52 m2 = 437 Euro	bouwkosten.nl	10,2 Euro/m2 x 52 m2 = 530 Euro	bouwkosten.nl
Ceiling												
Metal profiles for suspended ceiling	85 profiles	0,1 kg per profile	4 Euro per profile	340 Euro	8.5 kg	ALBES ceilings (Russia)	3 Euro/1 profile x 85 profiles = 255 Euro	bouwkosten.nl	4 Euro/1 profile x 85 profiles = 340 Euro	ALBES ceilings (Russia	5,5 Euro/1 profile x 85 profiles = 468 Euro	ALBES ceilings (Russia)
Ceiling finishing boards	28 m2 (1 tile =600x600 mm)	6 kg/tile	28 Euro/m2	784 Euro	468 kg	Taken from bouwkosten.nl	19,95 Euro/m2 x 27,7 m2 = 552,6 Euro	bouwkosten.nl	28 Euro/m2 x 27,7 m2 = 775,6 Euro	bouwkosten.nl	34,8 Euro/m2 x 27,7 m2 = 964 Euro	bouwkosten.nl
Floor												
Finishing layer	25 m2		3,5 Euro / m2	87,5 Euro	600 kg		17 Euro/m2 x 25 m2 = 425 Euro	teohim.ru	17,7 Euro/m2 x 25 m2 = 442,5 Euro	prompol.ehg.su	33,3 Euro/m2 x 25 m2 = 833 Euro	evropoll.nl
draft layer (insulation layer)	25 m2		17,4 Euro/m2 -> discount 30 % from 70 m	300 Euro		Taken from bouwkosten.nl	17,4 Euro/m2 x 25 m2 = 435 Euro	teohim.ru	26 Euro/m2 x 25 m2 = 650 Euro	bouwkosten.nl	39 Euro/m2 x 25 m2 = 975 Euro	bouwkosten.nl
Bathroom pod												
Metal wall frame railings	10	0,3 kg per 1 rail	4 Euro per profile	40 Euro	3 kg	Knauf (Germany)	2,5 Euro/profile x 10 profiles = 25 Euro	knauf.com	4,35 Euro/profile x 10 profiles = 43,5 Euro	knauf.com	5,8 Euro/profile x 10 profiles = 58 Euro	knauf.com
Gipsum-fiber board (2500x1200x12,5 mm)	5	31,5 kg / board	45,15 Euro / board	225,7 Euro	157.5 kg	Knauf, taken from bouwkosten.nl	31,5 Euro/board x 5 = 157,5 Euro	Knauf (Russia)	37,3 Euro/board x 5 boards = 186,5 Euro	snabmsk.ru	45,15 Euro/board x 5 = 225,7 Euro	bouwkosten.nl
Ceramic finishing tiles walls	17,6 m2	15 kg / m2	17 Euro / m2	300 Euro	264 kg	Taken from bouwkosten.nl	10 Euro/m2 x 17,6 m2 = 176 Euro	shopceramica.ru	17,3 Euro/m2 x 17,6 m2 = 305 Euro	bouwkosten.nl	37 Euro/m2 x 17,6 m2 = 651 Euro	xplit.ru
Ceramic finishing tiles floor	3,5 m2	23,3 kg / pack -> 3 packages	39,8 Euro / m2	139 Euro	70 kg	Taken from bouwkosten.nl	18,5 Euro/m2 x 3,5 m2 = 64,75 Euro	plitka-sdvk.ru	37 Euro/m2 x 3,5 m2 = 130 Euro	santa-keramika.ru	47 Euro/m2 x 3,5 m2 = 164,5 Euro	plitka-sdvk.ru
Watercloset	1			500 Euro	37 kg	Taken from bouwkosten.nl	275 Euro	kranik.ru	450 Euro	kranik.ru	500 Euro	kranik.ru
Shower pod	1 (800x80x500 mm)			250 Euro	48 kg	Taken from bouwkosten.nl	130 Euro	ruspanel.ru	260 Euro	hatria.ru	360 Euro	hatria.ru
Sink	2	6 kg /sink	30 Euro / sink	60 Euro	12 kg	Santek (Russia)	60 Euro	santek.ru	140 Euro	santek.ru	200 Euro	santek.ru
Door	1			110 Euro	14 kg	Rem-Sovet (Russia)	110 Euro	Rem-Sovet (Russia)	160 Euro	Rem-Sovet (Russia)	220 Euro	Rem-Sovet (Russia)
Light	4 (LED lights inside ceiling)		60 Euro / spot	240 Euro	9 kg	Lucide (Belgium)	150 Euro x 2 lights = 300 Euro		240 Euro x 2 lights = 480 Euro		350 Euro x 2 lights = 700 Euro	
Ward medical furniture and equipment												
Patient bed	1			4.700 Euro	125 kg	Linet Eleganza (Italy)	2.800 Euro	phc-online.com	4.700 Euro	Linet Eleganza (Italy)	5.200 Euro	phc-online.com
Caregiver entrance sink	1			330 Euro	11.5 kg	Duravit (Germany)	300 Euro	Duravit (Germany)	330 Euro	Duravit (Germany)	460 Euro	phc-online.com
Headwall system (medical gases, life system control, etc)	1			5.400 Euro	52 kg		4500 Euro		5.400 Euro		6.300 Euro	
Medical gas system	1			660 Euro								
Medical gas pipes	20 m (length)		13.4 Euro/1 m length	268 Euro		Taken from bouwkosten.nl	13,4 Euro/m length x 20 m length = 268 Euro	bouwkosten.nl	15,6 Euro/m length x 20 m = 312 Euro	bouwkosten.nl	19 Euro/m length x 20 m = 380 Euro	bouwkosten.nl
Ventilation pipes												
Main ceiling light	1			85 Euro	4 kg		Included in lights		Included in lights		Included in lights	
Bed light	2			40 Euro	1 kg		40 Euro x 2 lights = 80 Euro		65 Euro x 2 lights = 130 Euro		75 Euro x 2 lights = 150 Euro	
Visitor sofa	2			120 Euro	3 kg		120 Euro x 2 = 240 Euro		300 Euro x 2 = 600 Euro		410 Euro x 2 = 820 Euro	
Table (foldable)	1		60 Euro	60 Euro	25 kg		60 Euro		60 Euro		80 Euro	
Chair	2	5 kg per chair	40 Euro / chair	80 Euro	10 kg		50 Euro x 2 chairs = 100 Euro		90 Euro x 2 chairs = 180 Euro		120 Euro x 2 chairs = 240 Euro	
bed stend	1			120 Euro	7 kg		120 Euro		140 Euro		160 Euro	
Electrical radiator (heating system)	2	18 kg (1) + 9 kg (2)	100 Euro (1) + 360 Euro (2)	460 Euro	27 kg	Varmann (Russia)	219 Euro x 2 = 438 Euro		244 Euro x 2 = 488 Euro		379 Euro x 2 = 758 Euro	
HEPA filter (air cleaning and anti-bacterial environment)	1			542 Euro	15 kg	Tion (Russia)	542 Euro		658 Euro		702 Euro	
Fan-coil (central heating and ventilation system)	2 (this is the rule for hosp)	38 kg per unit	3.400 Euro per unit	6.800 Euro	76 kg	Daikin (Japan)	1.342 Euro x 2 = 2.684 Euro		3.400 Euro/unit x 2 = 6.800 Euro		3.800 Euro x 2 = 7.600 Euro	
Patient control status monitor system	1			1.420 Euro	5.5 kg	Aimed (China)	900 Euro		1.420 Euro		1.820 Euro	
Facade external panel	1 (13,3 m2)	42,4 kg / m2	25 Euro / m2	332 Euro	563.92 kg		245 Euro		350 Euro		510 Euro	
Metal frame (skeleton)												
Insulation layer												
Waterproofing membrane												
External finishing layer (metal casseste facade)												
Window	1			500 Euro	300 kg		550 Euro		870 Euro		1500 Euro	
TOTAL				**41.069 Euro**	**11.748 kg**		**20.964 Euro**		**33.501 Euro**		**44.132 Euro**	

(Source: Author, 2017)

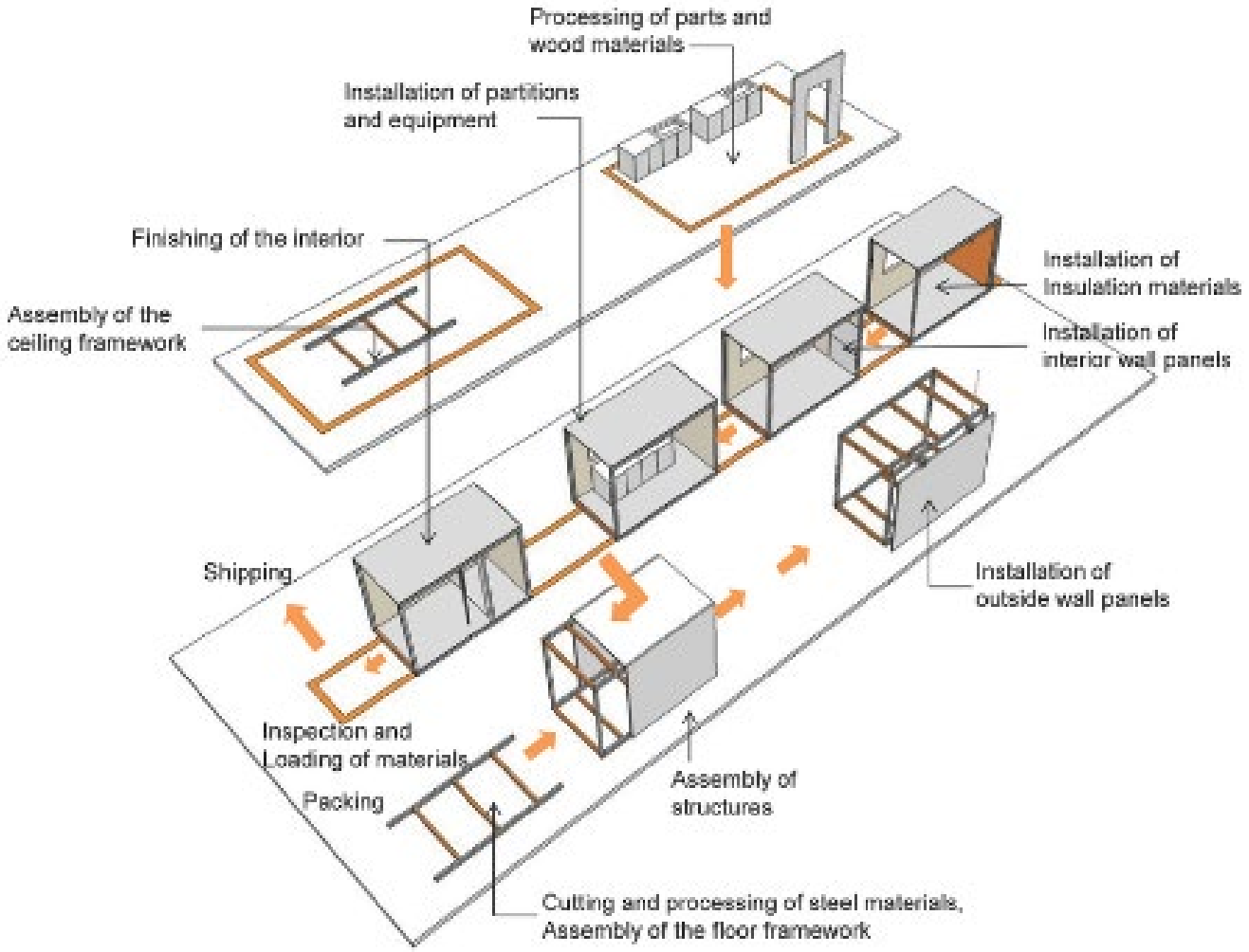
Plafondbekledingen onder gebouw-/dakoverstekken - 2 lagen gipsvezelplaten + stucwerk ceiling coverings include building / roof overhangs - 2 layers of gypsum fiber board + plaster incl. isolatie tegen onderzijde dakvloer – gedeeltelijk incl. insulation underneath roof deck - partially	165 m2	175,00	0 28.875 0 0 0	0,00 0,36 0,00 0,00 0,00
NSA-gebouw NSA building: - plafondafwerking -- onderzijde dakvloer in het zicht ceiling finish - lower roof deck in sight ** toeslag voor schoonwerk charge for cleaning work	285 m2	10,00	2.850 0 0	0,04 0,00 0,00
TOTAAL PLAFONDS (binnen en buiten) TOTAL CEILING (inside and outside)			**2.602.695**	32,86
TOTAAL BOUWKUNDIGE WERKEN TOTAL CONSTRUCTION WORK			**76.925.293**	971,28

(Source: Wiegerinck Architects, 2017)

Materials and components. Results

Parameter	Modular construction	Conventional construction
Installation costs	33 - 42 %	34 %
Costs of construc-tion elements	33 - 37 %	38 %
Costs of medical equipment	23 - 40 %	23 - 40 %

Workers and labor productivity. Getting data



(Source: www.sekisuiheim.com. 2017)

Number of operations, workers and men-hours required to produce 1 module

Workers and labor productivity. Getting data

Type of operation	Labor hour per module												
	Low	Medium	High	N of men/operation	Total hrs	Min price	Max price	Price 1	Price 2	Price 3	Price 4	Price 5	Source
Cut to size (Mill)	3	12	17	1	12								
Build floor	8	8	27	2	8								
Build window / door opening subassy	2	3	4	2	2								
Build partition walls	2	5	9	1	5								
Build side walls	3	5	7	1	5								
Build end walls	1	2	3	1	2								
Build marriage wall	2	3	3	1	3								
Set partition walls	2	3	5	1	3								
Set exterior & marriage walls	2	4	4	1	4								
Install rough electric in walls	7	7	17	1	7								
Build plumbing subassemblies	no data	no data	no data	1									
Instal rough plumb in wall & tubs	4	6	8	1	6								
Build subassemblies for roof	2	4	6	1	4								
Build roof / ceiling	6	10	13	2	6								
Instal rough plumbing for roof	6	10	13	1	10								
Instal rough electric in roof / ceiling	5	5	7	1	5								
Insulate roof	3	4	12	1	4								
Instal fascia & soffit	5	7	9	1	7								
Insulate walls	6	7	9	1	7								
Sheath walls	2	4	13	1	4								
Install windows & exterior doors	0,28h/m2=1,3 h/window	1,6	2,2	2	1.6								
Install siding & trim	no data	no data	no data	1									
Hang drywall on walls	4	7	18	1	7								
Tape & mud drywall	1	2	20	1	2								
Sand & paint	1	4	20	1	4								
Install cabinets & vanities	3	4	8	1	4								
Build finish plumbing subassemblies	8	12	22	1	12								
Install finish plumbing	4	5	12	1	5								
Install finish electric	2	2	4	1	2								
Build interior door subassemblies	1	1	2	1	1								
Install interior doors	2	3	4	1	3								
Install molding	3	4	12	1	4								
Install miscellaneous finish items	1	4	6	1	4								
Install floring	1	2	7	2	1								
Load shiploose	5	8	24	1	8								
Factory touch-up	1	2	4	1	2								
Install plumbing in floor	3	4	4	1	4								
Load module on carrier	4	5	9	Mashine									
Final wrap & prep for shipment	no data	no data	no data	2									
Build major shiploose subassemblies	2	3	4	2	2								
Total	117	181	366	46	170.6	16,7 Euro	21,4 Euro	16,7 Euro	19,4 Euro	19,6 Euro	20,4 Euro	21,4 Euro	statline.cbs.nl
	4,5 days (3 shifts / day)	6,8 days	14,5 days		7 days			non-western migrants	western immigrants	western immigrants	Dutch	Dutch	

(Source: Mullens M. A., Factory design for modular home building, 2011)

Workers and labor productivity. Results

Parameter	Modular construction	Conventional construction
Amount of hours to build a module (30m2)	24 hours (with all finishings)	15 hours (only external shell)
Amount of sq m built per day on site	170 - 300 m2	80 m2
Hourly wage	15,7 Euro / hour	14,4 Euro / hour

Transportation. Getting data

- Fixed operating costs (cost of truck, cargo and vechicle insurance)
- Variable operating costs (cost of fuel, cost of maintenance, daily costs)

Fixed operating costs	Price 1,minimum, Euro	Price 2, most expected one, Euro	Price 3, maximum, Euro	Source
Cost of vehicle ownership	29,750	39,500	52,500	toprtucks.nl
Cost of vehicle rent, per month	639/21 working days = 30,4 Euro/day	658/21 working day = 31,3 Euro/day	1541/21 working day =73,3 Euro/day	toprtucks.nl
VAT of vehicle ownership = 21 %	6,247	8,085	11025	toprtucks.nl
VAT of vehicle rent = 21 %	134 Euro	138 Euro	323 Euro	
Cost of lorry	18,750	19,750	24,500	toprtucks.nl
Cost of lorry rent, per month	528/21 working day = 25,1 Euro/day	551/21 working day = 26,2 Euro/day	690/21 working day = 33 Euro/day	
VAT of lorry ownership = 21 %	3,937	4,147	5,145	toprtucks.nl
VAT of lorry rent = 21%	111 Euro	115 Euro	145 Euro	toprtucks.nl
Funding scheme (vehicle)	Bank loan	Bank loan	Bank loan	
Cost of license ownership	9,000 Euro for 1st truck	5,000 Euro for every other truck		
Road tax	1,250/year= 3,42 Euro/day	125/month	33/week, 8/day	eurovignettes.eu
Cargo insurance	0.1-0.3 % from cargo cost + 0,5% as franchise = 0,8% from cargo cost			
Vehicle insurance	210 Euro/6 months=1,16 Euro/day	800 Euro/year= 2,2 Euro/day	2000 Euro/year = 5,5/day	
Vehicle parking cost	1,200/Year/365=3,2 Euro/day			
Cost of technical inspection of the vehicle	80 Euro/year/365=0,2 Euro/day	158 Euro/year= 0,43 Euro/day	260 Euro/year= 0,71 Euro/day	
Total fixed costs for selected route (truck ownership) for 1 module	**68.191 Euro**			
Total fixed costs for selected route (truck lease)	**725 Euro**	**814 Euro**	**1000 Euro**	

Variable operating costs	Price 1, Euro	Price 2, Euro	Price 3, Euro	Source
Fuel price	1,34 Euro/1 liter (diesel)	1,69 Euro/liter (95)		statline.cbs.nl
Average fuel consumption for truck/100 km	31,9 liters x 2(round trip) = 63.8 liters	33,2 liters x 2 (round trip) = 112,2 Euro	35 liters	volvo.com
Cost for tires	85 Euro	110 Euro	185 Euro	
Maintenance cost	800 Euro/year/365=2,19 Euro/day	1000 Euro/year = 2,73 Euro/day	3.500 Euro/year/365 = 9,6 Euro/day	
Repair cost	900 Euro/year = 2,46 Euro/day	2.500 Euro/year = 6,85 Euro/day	6.600 Euro/365 = 18 Euro/day	
Tolls (пошлины)				
Driver wage x2, 2d driver is required for modules > 3,5 m width	1718 Euro/month = 78 Euro/day x2 = 156 Euro	2134 Euro/month = 97 Euro/day x2 = 194 Euro	3223 Euro/month = 153 Euro/day x2 = 306 Euro	
Driver insurance	1.350 Euro/year = 3.7 Euro/day	1950 Euro/year = 7.5 Euro/day	2.500 Euro/year = 6.2 Euro/day	
Police guard along the route	1,5 Euro/km = 150 Euro/route	2 Euro/km = 200 Euro/route		
Official permission for transportation of non-dimencional cargo	660 Euro	660 Euro		negabaritof
Taxes				
Ocupation tax	0,17 Euro/ 1 km (Germany)			
Communication costs (telephone, internet)	10 Euro/month	10 Euro/month	10 Euro/month	
Truck wash	55 Euro	64 Euro	69 Euro	
Fines				
Daily costs				
Accomodation costs				
Meals	20 Euro/day	30 Euro/day	40 Euro/day	
Total variable costs for selected route	**1.110 Euro**	**1.397 Euro**	**1.534 Euro**	
Total costs for selected route (truck ownership)	**69.126 Euro**			
Total costs for selected route (truck lease)	**1.835 Euro**	**2.211 Euro**	**2.534 Euro**	

Transportation. Results

Low transportation cost of module: **1.835 Euro**

Average transportation cost of module: **2.211 Euro**

High transportation cost of module: **2.534 Euro**

On-site works. Getting data

- **Main on - site activities in modular consruction - foundations and cranage**

Parameter	Quantity	Time (duration)	Comments	Price 1, Euro	Price 2, Euro	Price 3, Euro	Source
Excavation							
Excavation personnel	3 workers	2 hours		38,3 Euro/hour = 76,6 Euro	45 Euro/hour = 90 Euro	51 Euro/hour = 102 Euro	bouwkosten.nl
Excavator	1 mashine	2 hours		65,75 Euro/hour = 131,5 Euro	68,25 Euro/hour = 136,5 Euro	71,55 Euro/hour = 143,1 Euro	bouwkosten.nl
Weel loader (buldozzer)	1 mashine	2 hours		61,4 Euro/hour = 122,8 Euro	68,85 Euro/hour = 137,7 Euro	79,8 Euro/hour = 159,6 Euro	bouwkosten.nl
Foundation construction							
Piles	8 piles			8,75 Euro/m length; 5 m pile x 8,75 x 8 = 350 Euro	13 Euro/m length; 5 m pile x 12 x 8 = 480 Euro	15 Euro/m length; 5 m pile x 14 x 8 = 560 Euro	bouwkosten.nl
De-watering site		0,32 men-hour/unit					
Site drainage							
Sewer pipe system, concrete	10 m			31 Euro/1 m length = 310Euro	38 Euro/1 m length = 380 Euro	43 Euro/1 m length = 430 Euro	bouwkosten.nl
Sewer pipe, fittings	5/module			5 Euro/fitting = 25 Euro	25 Euro/fitting = 125 Euro	47 Euro/fitting = 235 Euro	bouwkosten.nl
Crane (40-75 tons capacity required)	1 crane	1 hour/module		470 Euro/8 hours = 59 Euro/hour	566 Euro/8 hours = 71 Euro/hour	700 Euro/8 hours = 88 Euro/hour	bouwkosten.nl
On-site personnel workers for module installation	2 persons	1 hour/module		11,8 Euro/hour	13.26 Euro/hour	14.88 Euro/hour	EFBWW (EU)
Personnel for technical installations and connections	2 persons			32 Euro/hour = 64 Euro	46 Euro/hour = 92 Euro	53 Euro/hour = 106 Euro	bouwkosten.nl
Construction manager	1 person			14 Euro/hour	19.8 Euro/hour	23.7 Euro/hour	indeed.nl
Assembly-dismantling staff accommodation (site office)	1 site-office			81 Euro/unit	137 Euro/unit		bouwkosten.nl
Interior finishings	2 hours			37,2 Euro/hour	41.86 Euro/hour	46,9 Euro/hour	bouwkosten.nl
Landscape design and finishes							bouwkosten.nl
Pavement	5 m2			19 Euro/m2 = 95 Euro	22 Euro/m2 = 110 Euro	24 Euro/m2 = 120 Euro	bouwkosten.nl
Processing of soil, sand, gravel	78 m3			8 Euro/m3 = 624 Euro	9 Euro/m3 = 702 Euro	9 Euro/m3 = 702 Euro	bouwkosten.nl
Trees	1						
Module installation	1	0,2 h/module	Price included in crane and personnel				
Waste disposal from construction site (in containers)	1		Container dimentions:	82 Euro	140 Euro	164 Euro	bouwkosten.nl
			2.50 x 1.60 x 1.00 (3m3)				
			3.35 x 1.85 x 1.10 (6 m3)				
			3.60 x 1.90 x 1.60 (10 m3)				
Total				2.084 Euro	2.676 Euro	2.839 Euro	

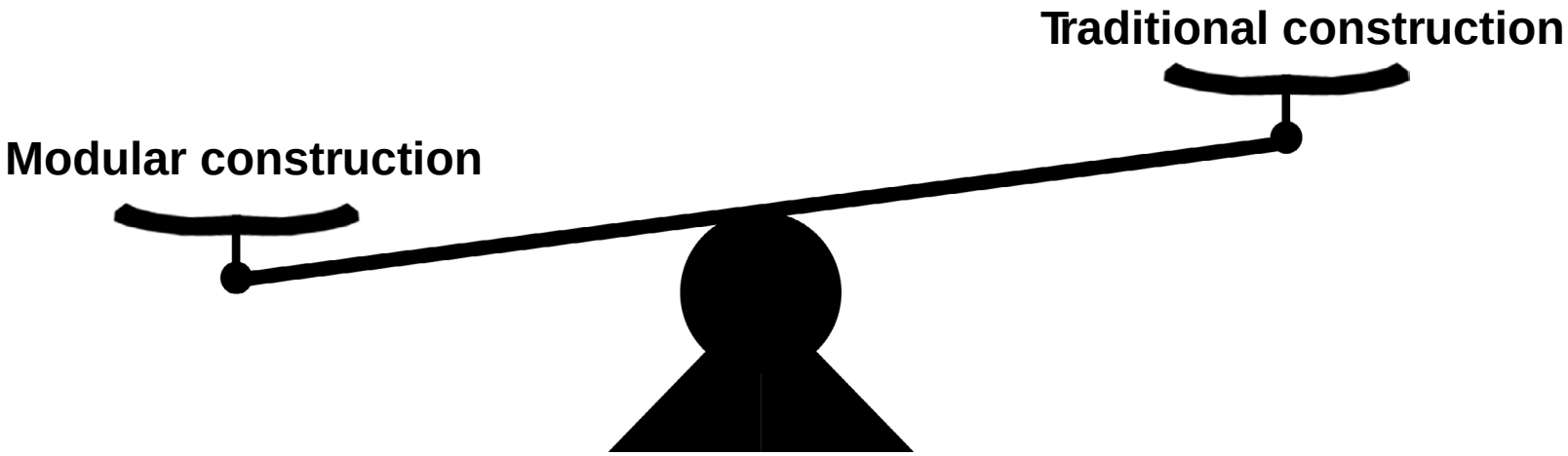
- **Excavation works**
- **Foundations**
- **Cranage of the module**
- **Site personnel**

On-site works. Results

Parameter	Modular construction	Conventional construction
Cost of foundation works as % from total budget	4%	4%
Amount of m2 constructed per day	180 - 300 m2 (6 - 10 modules / day)	Up to 80 m2

Savings in construction phase

Costs	**52.900 Euro / module 1800 Euro / m2**	**2500 Euro / m2**	**28 %**
Time	**180 - 300 m2 / day**	**Up to 80 m2 / day**	**80 %**



06. Use phase

Daily maintenance

Interior finishing: **32 %**

HVAC: **29 %**

Electricity: **13 %**

Exterior envelope: **13 %**

Water and plumbing: **10 %**

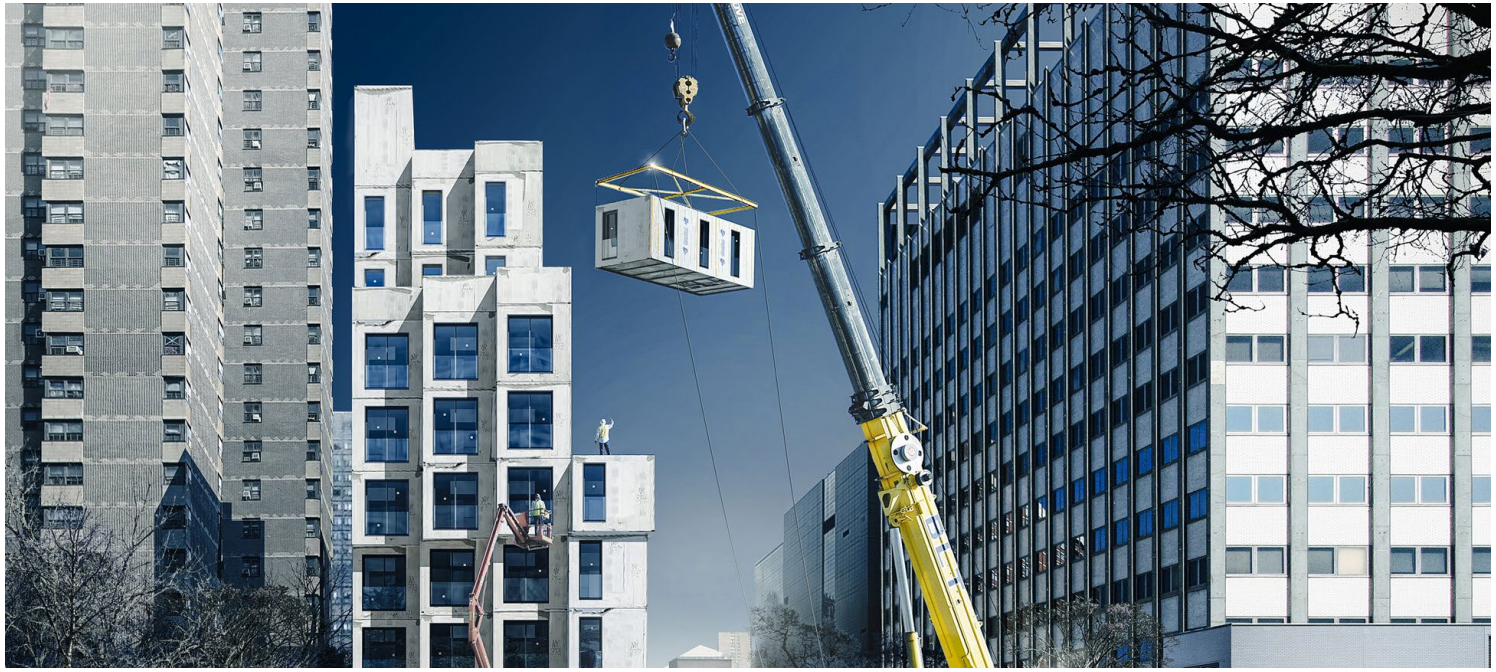
Low-voltage systems: **3 %**

Parameter	Modular construction	Conventional construction
Maintenance annual cost as % from construction budget	2 %	2 %
Warranty's period and nature	10 Years for all componnents	Highly depends on contractor and other factors

Refurbishment

Parameter	Modular construction	Conventional construction
Refurbishment costs savings	25 - 50 % from conventional one	Highly depends on the case
Refurbishment time savings	Highly depends on the case; Small changes takes a day	Highly depends on the case

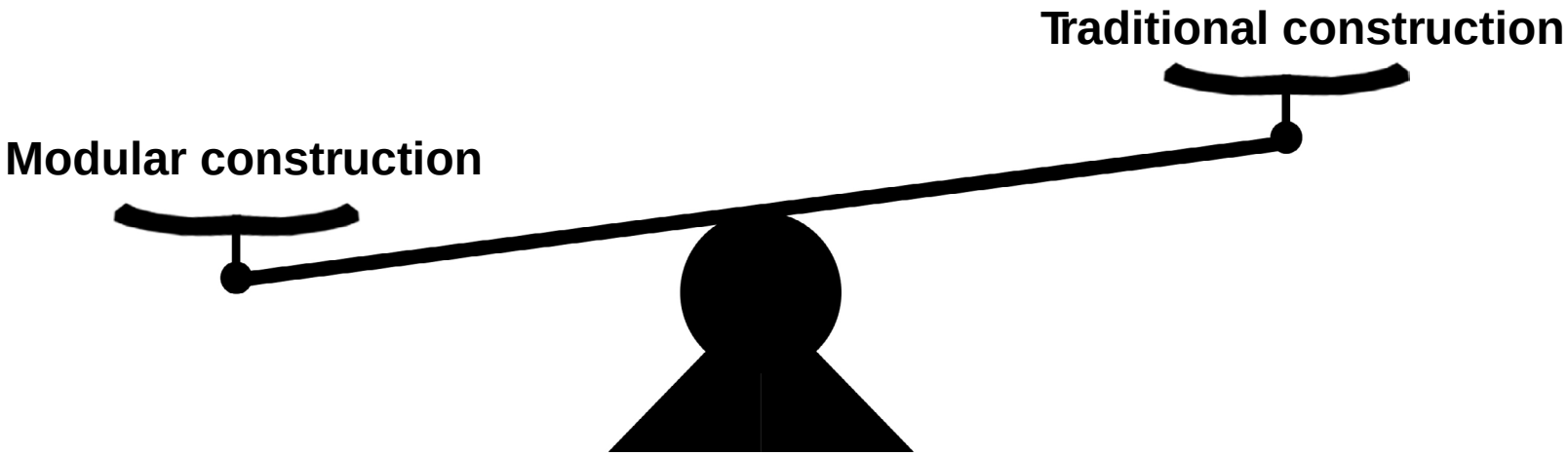
Re-location of the modules



Parameter	Modular construction	Conventional construction
Re-location costs of the module	4.800 - 6.700 Euro (10 - 15 % from total module cost)	Not applicable
Re-location time of one module	Depend on the new site	Not applicable

Savings in use phase

Parameter	Modular construction	Conventional construction
Annual maintenance costs	2 %	2 %
Refurbishment costs	25 - 50 % from conventional one	Highly depends on the case
Re-alocation costs	4.800 - 6.700 Euro per module (10 - 15 % from module)	Non applicable



07. Conclusion

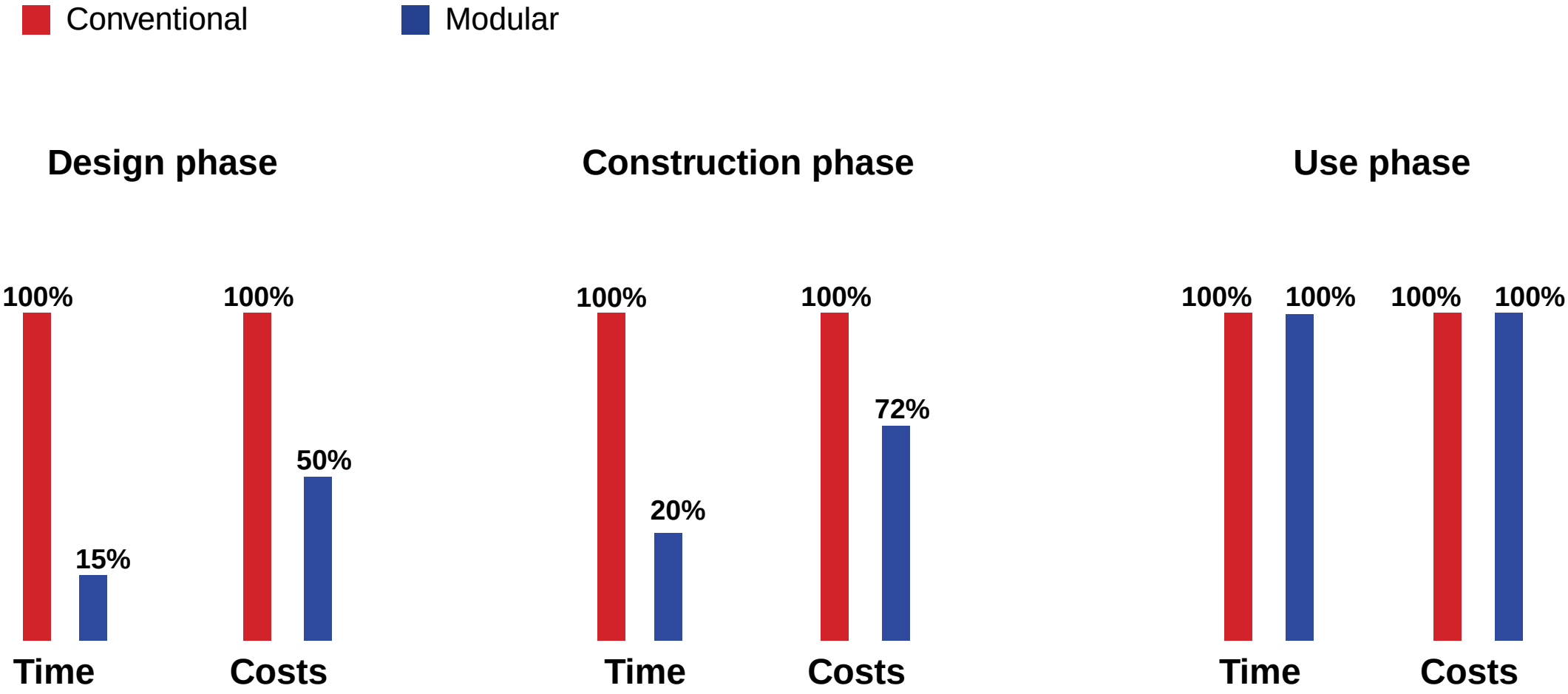
	Parameter	Modular construction	Conventional construction	Savings, %
Design phase	Costs	50 % from conventional design (3 - 4% of total budget)	6 - 8 % from total budget	50 %
	Time	0 - 15 % from conventional design	Depend on the case (minimum a year)	85 % - 100 %
Construction phase	Costs	52.900 Euro / module 1800 Euro / m2 *	2500 Euro / m2	28 %
	Time	180 - 300 m2 / day	Up to 80 m2 / day	80 %
Use phase	Costs	2 % / year from construction budget	2 % / year from construction budget	None
Refurbishment phase	Costs	25 - 50 % from conventional construction	Highly depends on the case	25 - 50 %
	Time	Highly depends on the case	Highly depends on the case	Depends on the case

* - including VAT (21 %)

Answering research questions

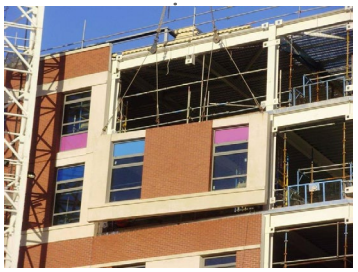
Main research question of the project:

To which extent are prefab solutions in healthcare design and construction processes are more economically feasible than traditional methods?

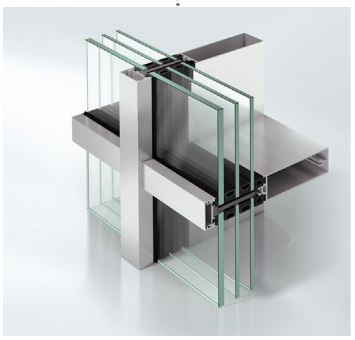


Are the in-between scenarios?

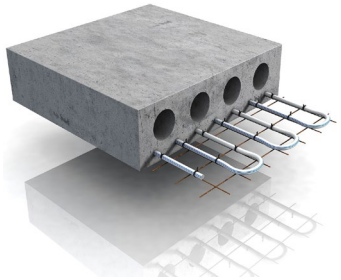
Prefab facades



Window frames



Floor slabs



Steel constructions

Bathroom pods

Flatten kit of elements

To what extent is prefab used in current situation in healthcare sector?

(Source: Cadolto, 2016)

- **Fully modular hospitals exist across Europe**

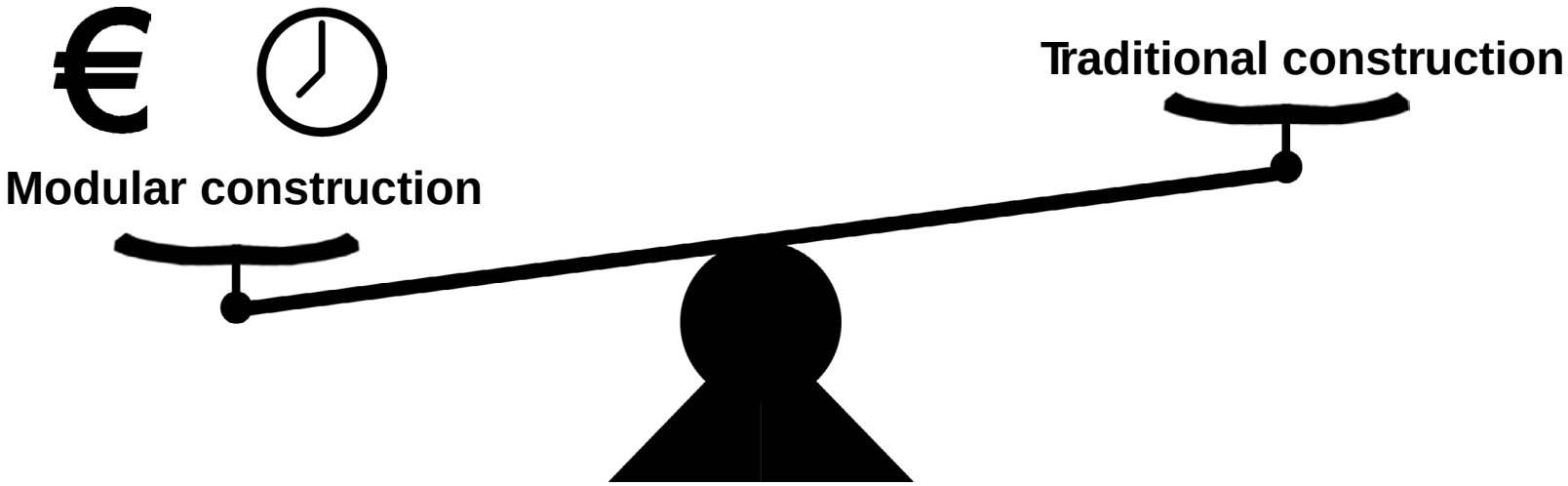
- **Conventional hospital construction mainly uses prefab facades, floor slabs and small components**

To what extent is enlarging the amount of prefab elements feasible considering the design and construction process?

- **Fully modular hospital complex is more feasible in design and construction process, comparing to traditional methods**

Which parts of the healthcare facilities are mostly suitable for implementation prefab solutions in a cost-effective way?

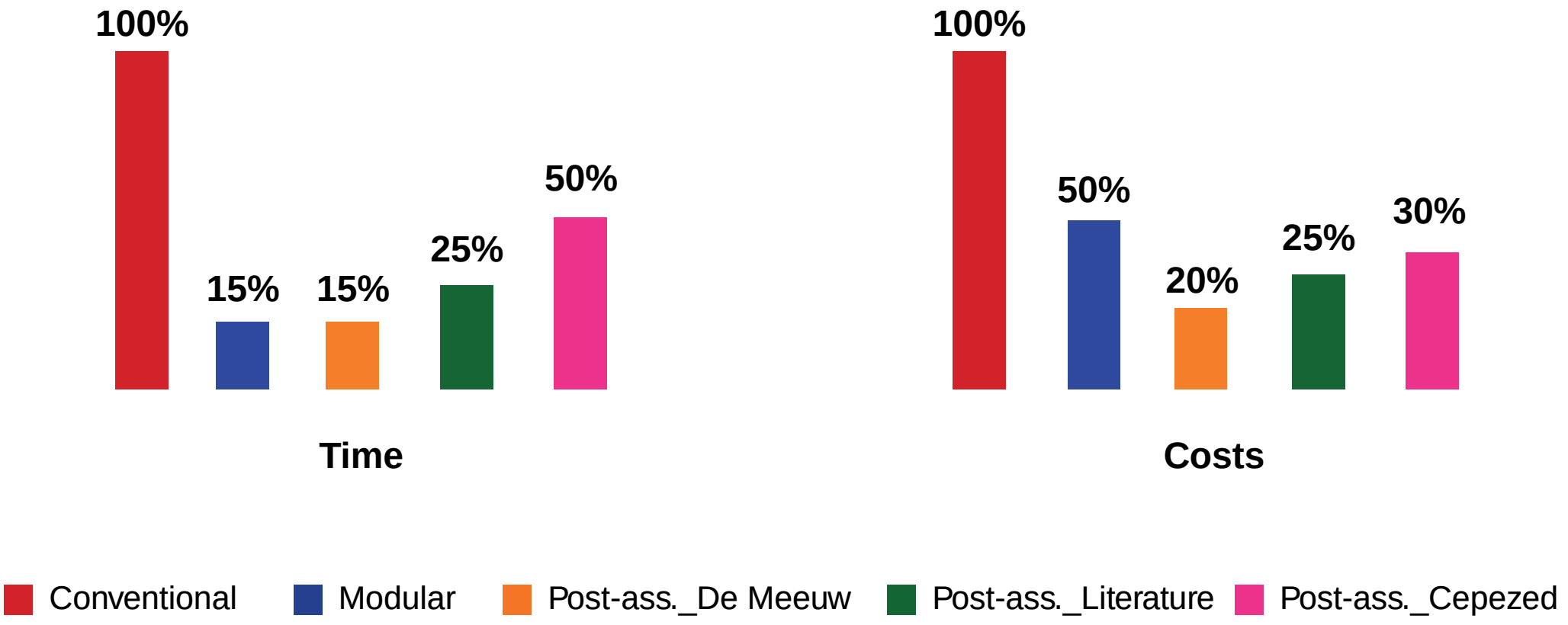
- **High-tech departments, such as surgery and MRI rooms are mostly suitable for modular development based on indoor assembly process**


Traditional construction
Modular construction

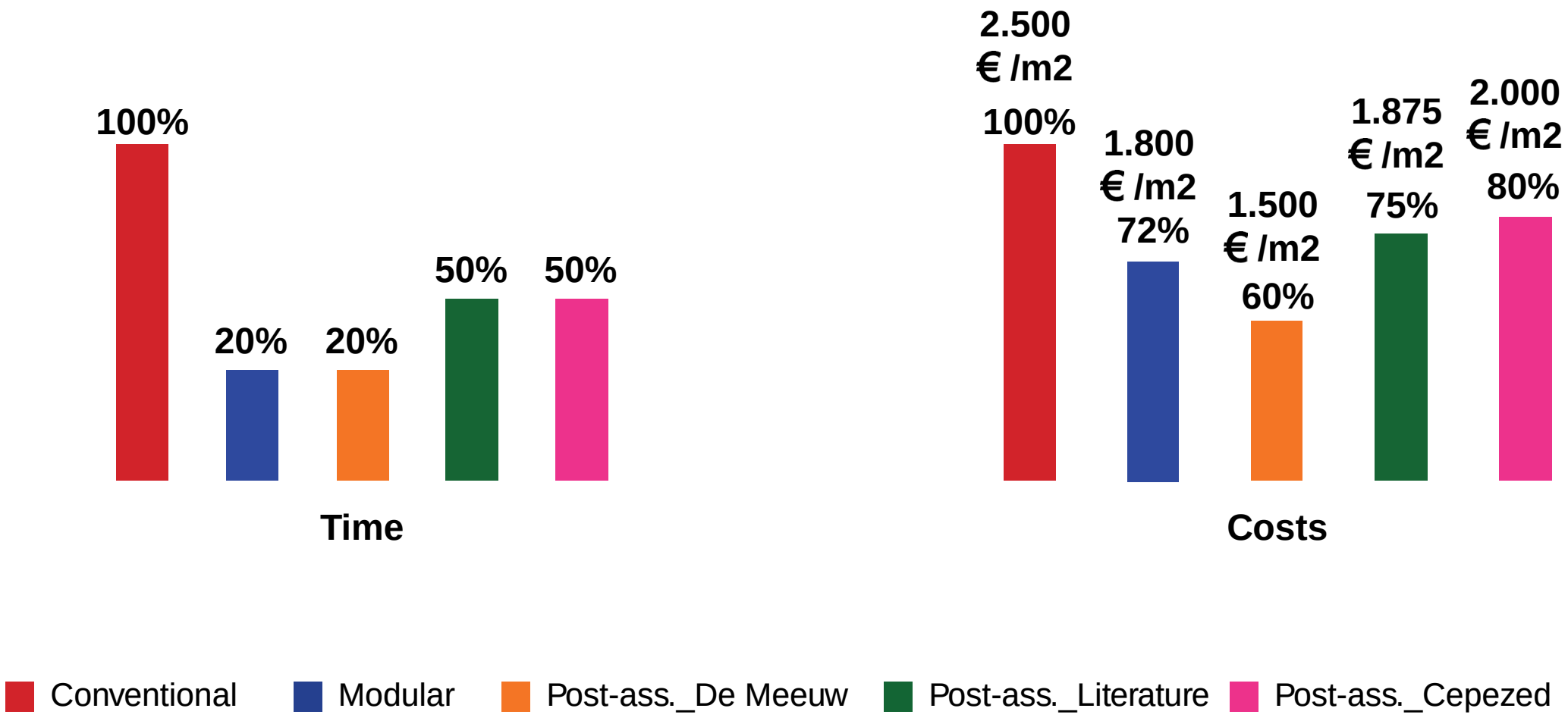
08. Validation of research results

Research results vs experts' opinion

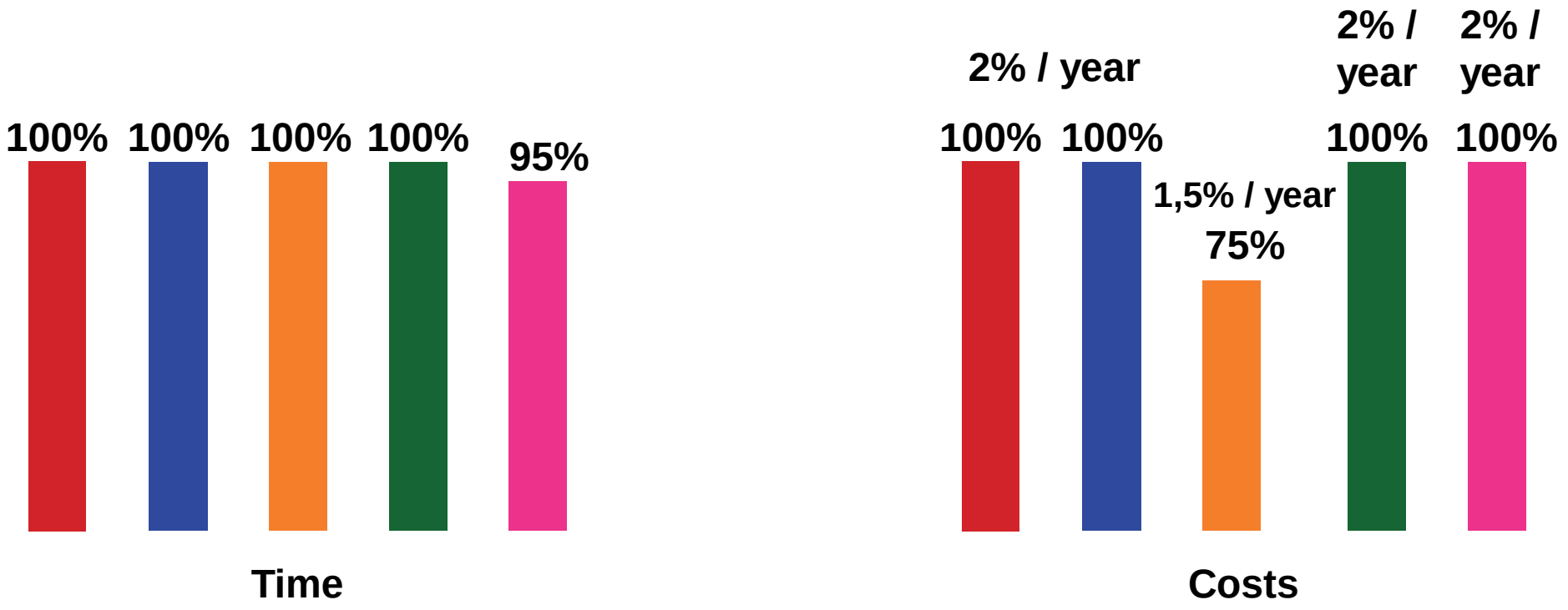
Design phase



Construction phase



Use phase


100%
100%
100%
100%
95%
Time
2% / year
100%
100%
1,5% / year
75%
2% / year
100%
2% / year
100%
Costs
Conventional
Modular
Post-ass._De Meeuw
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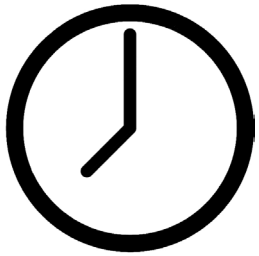
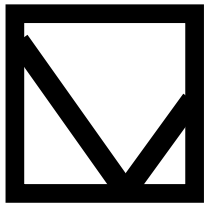
09. Reflection and further research

Main benefits of modular construction



Time

Costs



Quality ?