Preparing for a modular retrofit future of walk-up apartments with the use of computational design

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ABSTRACT

Due to the NECP a lot of houses are in need of retrofitting. In 2016, the Netherlands had 799,956 apartments that were built between 1906 and 1965. Approximately, 10.47 percent of the total Dutch housing stock. A large amount which consists of porch houses. The houses are poorly insulated due to hasty and savings in construction. This research focuses on walk-up apartments built after the Second World War. The aim is to define how to improve the renovation process of walk-up apartment buildings through a modular facade system generated with the use of computational design. The study will mainly focus on; construction method, current use, possibility of extending/reinforcing the facade, adaptability, similarities in typology/construction and the possibility of mass production of facade elements. MUWI, Pronto, BMB, Vam, Rottinghuis and Wilma are the preferable structure types. Renovation through prefabricated module systems or extension of the façade is preferable. These modules or extensions are connected with steel brackets on a separate structure. By integrating MFRRn into the prefabricated modular system for expansion, the building will become more sustainable by applying higher insulation requirements and air treatment, which will generate a better living environment. the amount of case studies in which parametric tools are used for retrofitting is limited. Where, zero case studies were found in which parametric tools are used for retrofitting different buildings within the same typology. Lastly, generative design can help in retrofitting projects for optimization; daylight, buzz, visual and audio distortion, floor plan and façade elements.

KEYWORDS: *RENOVATION, COMPUTATIONAL DESIGN, RETROFIT WALK-UP APARTMENTS, MODULAR FACADE*

1. INTRODUCTION

The western world has been dealing with rapid urban densification in the. Last decades (Erik Koomen, 2020). Several cities deal with poor living conditions due to deferred maintenance and a hasty need for more housing. Additional housing is needed to meet housing demands and improvements to existing housing are necessary to comply with the Paris Agreement or the National Energy and Climate Plan (NECP), This plan proposes to reduce the total greenhouse gas emissions with 80% by 2050 and 90% reduction in gas emissions produced by buildings (World Green Building council, 2021)

The social housing stock, largely owned by housing associations, is also affected by the NECP, which embraces the ambition to achieve CO2 neutrality of its homes by 2050. The social housing stock that usually consists of row housing of small apartments (walk-up or gallery). There are two solutions for the social housing stock: demolition or renovation. During demolition, a large amount of raw materials are released during the process, in particular due to poor recycling of materials, resulting in higher emission values. Most renovation solutions available on the current market target only a fragment of the housing stock: terraced houses. This can be explained by the large amount of row housing in the Netherlands and the fact that these houses are relatively easy to renovate due to the fact that they can be renovated one after another. (Leo Oorschot, Lidwine Spoormans, Sabira El Messlaki, Thaleia Konstantinou, Tim de Jonge, Clarine van Oel, Thijs Asselbergs, Vincent Gruis and Wessel de Jonge, 2018). Which leaves a gap in the rest of the existing building stock. This research focuses on renovation of walk-up apartments after the second world war.

Because in terms of construction they offer quite - good basic values for apartments (Inge Blom, LaureI tard, Arjen Meijer, 2010). Renovation of walk-up apartments is different from terraced houses because it is not likeable to renovate walk-up apartments one after another while this is doable with row housing. Therefore, the main research question is: how can the renovation process of walk-up apartments be improved by using modular facade components generated by computational designs?

To further specify different topics within this main research objective, 6 sub-questions are listed:

Typologies and renovation of walk-up apartments:

1. Which different typologies for walk-up apartments from inter/post-war are constructed and usable for modular facade retrofitting?
2. What are the existing renovation techniques for walk-up apartments?

Modularity and modular facade systems for renovation in the built environment:

3. Which modular systems can be used for renovation of walk-up apartments?
4. How are modular facade systems attached to buildings?

Computational design implementations in the building environment:

5. Are there existing projects in which computational design methods are used for retrofitting of existing buildings?
6. How can computational design methods support a generative renovation design for walk-up apartments?

The main goal in renovation projects is to achieve better energy emissions, living conditions and solve the housing shortage. The lifespan of materials in buildings differs as described by Brand Steward. He states '*A well-designed building consists of multiple layers of built component life*' (Brand S. 1994). The skin of the building needs a replacement every 20 years, but the construction could potentially last 30 - 300years. Revitalization and reconfiguration cost a lot of material, time and money, because the façade is in need of a new transformation every 20 years. Within this paper a new renovation approach is chosen and designed. A modular approach could prove to be more (cost)effective if the walk-up apartments were transformed to meet contemporary requirements, prepared for easy, modular future transformations. The aim is to realize transformations in the future with lower costs, more customization and lower emissions.

2. Results

2.1 Which different typologies for walk-up apartments from inter/post-war are constructed and usable for this type of retrofit?

"*The classification of objects, structures, or specimens by subdividing observed populations into a theoretical sequence or series of groups (types) and subgroups (subtypes) according to consideration of their qualitative, quantitative, morphological, formal, technological, and functional attributes.*" (The Concise Oxford Dictionary of Archaeology. Oxford Univ.Pr., 2002.) According to the Oxford dictionary of Archaeology walk-up apartments can be considered a typology in which subtypes can be divided based on their technical aspects. Walk-up apartments are categorized by a porch, which is A porch is an open space adjacent to the entrance of a building (Aeneas, Toolkit Existing Buildings, 2009). Nearly all porch houses built in the post-war period consist of 3-4 floors as this was the highest number of floors where no elevator was required, saving a lot of money and time (Bouwhulpgroep, 2013) (Leo Oorschot, Lidwine Spoormans, Sabira El Messlaki, Thaleia Konstantinou, Tim de Jonge, Clarine van Oel, Thijs Asselbergs, Vincent Gruis and Wessel de Jonge, 2018, Flagships of the Dutch Welfare State in Transformation: A Transformation Framework for Balancing Sustainability and Cultural Values in Energy-Efficient Renovation of Postwar Walk-Up Apartment Building). Because almost all porch houses are made to be built as efficiently as possible due to the enormous demand for homes.

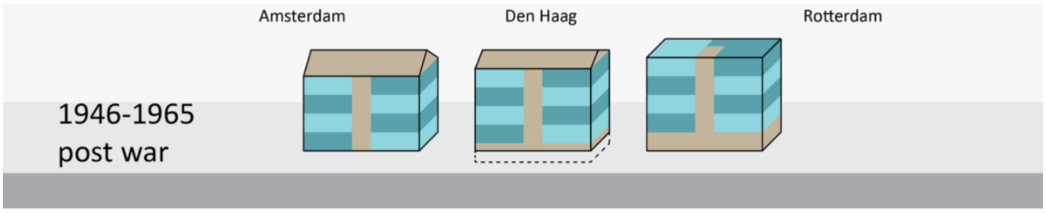


Figure 1. Different typologies of walk-up apartments from after the 2nd World War in the Netherlands.

In the construction of the system houses, the aim was to achieve a better cost-quality ratio and a larger production volume in the event of a shortage of labor capacity (skilled labor). The key lay in repetition and prefabrication. In total, about seventy systems appeared on the scene between 1948 and the early 1970s. Only half of these were of any size (more than 1000 homes) (Bouwhulpgroep, 2013). In 1975 there were still 21 systems with a total of approximately 225 thousand homes. However, some systems were only used in the construction of terraced houses or gallery apartments. After leaving out the "assembly structure" of various small parts with the help of metal pillars. There are 10 major system types left. These systems are categorized and assessed on various aspects (see Table 1).

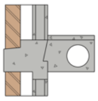
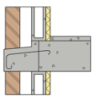
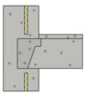
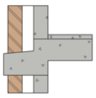
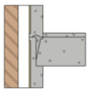
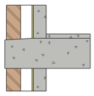
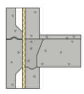
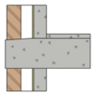
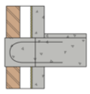
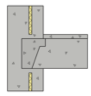
System	MUWI	Pronto	Coignet	RBM	BMB (Baksteen Montage Bouw)	Korrelbeton	VAM	Rottinghuis	Wilma	Welschen
Figure										
Amount of housing	36685 houses	17812 houses	31378 Houses	32292 Houses	+/- 30000 houses	15322 houses	14000 houses	17000 houses	12579 houses	5602 Houses
Percentage of total housing	11%	5%	9%	9%	9%	4%	4%	5%	3%	1%
Type of housing	53% porch 46% gallery 1% rest	32% Single Family house 62% porch 4% gallery 2% rest	Single family house 25% porch Gallery	Single family house porch gallery	Porch Gallery	75% porch 25 % single family house	Porch	50% porch 50% gallery	Single family house porch gallery	Single family house Porch
Construction technics System recognizability	Hollow light concrete blocks filled with gravel concrete	Stack construction, two-man blocks that are laid in half-brick bond, core of gravel concrete	Concrete is the basic material for load-bearing reinforced walls and floors	RBM 1 = setting and casting RBM 2 = casting construction, the walls are first poured using steel molds	Whole or half story height prefab concrete wall elements	Standardized wooden formwork and poured concrete with a granular aggregate	Element construction, light concrete prefabricated wall elements the floor is placed and the cavities are poured together	Element construction, medium-rise buildings, prefabricated concrete walls and floors, facade is masonry	Casting construction, formwork method with steel for the walls	Cast building facades, floors and skeleton entirely of concrete
Floor construction technics	Floors are made of prestressed concrete beams with filler blocks	system floor / sandwich floor	reinforced concrete floor and poured with wall anchors	wooden table placed on which the floor is poured, when cured wooden table is lifted out of the building	masonry floor slabs	slab floors (do not belong to the granular concrete system)	floor finish was still necessary, prefab floor elements	prefab floor plate	Floors wooden formwork where concrete is poured	floor plates were made separately on the construction site
Demolishment	<5% demolished	5-7 % demolished	>50% demolished	Unknown	<5% demolished	high demolition schedule	5-20% demolished	Unknown	Unknown	high demolition schedule
Floor plans	different types of floor plans 2 - 5 rooms apartments	4 - 5 - 6 Rooms Apartments	standardized 4 rooms apartments (Is experienced as unpleasant)	standardized 4 rooms apartments	5 - 6 Rooms Apartments	4 – 5 Rooms Apartments	2 and 4 Rooms Apartments	6 and 7 Room Apartments	7 Room apartments	4 – 5 Rooms Apartments
Improvement / renovation costs	improvement sum 60,400 total renovation 125,000	Improvement sum 94,000 total renovation 124,000	Unknown	Unknown	Improvement sum 61,220 Total renovation Unknown	Improvement sum 50000 -70000 total renovation Unknown	Unknown	Improvement sum 90000 euro Total renovation Unknown	Improvement sum 35,000 -115,000 Total renovation Unknown	Improvement sum 42,700 Total renovation Unknown
Wall characteristics	cavity wall innovation between 1954-1959	3cm thick insulation	2-2.5 centimeters thick polystyrene insulation	air cavity	cavity + 1cm polystyrene	plaster layer 1955 brick cladding 1962 cavity construction	different finish type	masonry front cover	-	-
Notes for renovation	Renovations seems to work		several structural problems, gray appearance, poor finish, demolition within 30 years	not a fixed size, which means that the RBM comes in different appearances and there is no typical recognizable appearance	houses of reasonable size, therefore also good to tackle on the inside	sober appearance	many possibilities with merging 3 to 2 apartments per floor		chance of improvement due to floor plan mainly at gallery	currently renovation project in Rotterdam, sporadic neighborhoods only exist
Standardization needed for tool	floor plan and standard sizes	floor plan and standard sizes	floor plan and standard sizes		floor plan and standard sizes	floor plan and standard sizes	floor plan and standard sizes	floor plan and standard sizes	floor plan and standard sizes	floor plan and standard sizes
Detailing										
Useable for retrofitting	Good	Good	Bad	Bad	Good	Good/Neutral	Good	Good	Good	Good/Neutral

Table 1. Different building systems for post war walk-up apartments

Table 1 defines the different building systems of the post-war walk-up apartments. It can be concluded that of these 10 building systems, 8 building systems can be used for this type of adaptation. This is due to the massive amount of demolition that the Coignet system has already undergone or the inconsistent dimensions of the RBM buildings. The Korrelbeton and Welschen types score Good/Neutral because there is a high demolition schedule, but the demolition has not yet taken place. There are 8 favorable building systems for a modular renovation due to their repetition and systematics. These building systems are: MUWI, Pronto, BMB, Korrelbeton, Vam, Rottinghuis, Wilma and Welschen.

2.2 What renovation techniques are there for walkable apartments?

Renovation will become more important in the coming decades as the value of more raw materials increases, this is a result of the NECP. Because demolition and new construction will require more raw materials, CO2 emissions will be higher and shortages will have to leak into other areas. The heavy concrete foundation of post-war homes is usually suitable for renovation (Table 1). '*The most missing items of post-war homes are mainly found in: high energy consumption, insufficient ventilation, overheating and insufficient thermal comfort*' (Ligia Mihaela Moga, Adrian Bucur, and Ionut Ian, 2021). Most of these problems can be solved with facade/roof renovation systems. The Building Science and Technology Lab state that there are four different facade renovation systems (EA, ECBCS, 2011a):

- External composite insulation system (ETICS)—traditional measure, in which insulation panels are mounted manually on site and are covered with plaster.
- Rear ventilated façade system—a manually procedure done on site consisting of insulation brought up between laths and fixed with a mounting system, being covered with different claddings.
- Partly prefabricated façade system—a prefabricated substructure with blown in insulation with an exterior cladding which is also prefabricated or is installed on site.
- Prefabricated module system—fully prefabricated panels, assembled in a factory, transported and mounted on site.

Contrary to the Building Science and Technology Lab (ECBCS, 2011a), it can be suggested that there is a fifth option for façade renovation. Expansion on the existing facade does not directly affect the original facade, but improves; high energy consumption, insufficient ventilation, overheating and insufficient thermal comfort. The approach of 'grand parc Bordeaux' and 'de la Tour Bois le Prêtre' are good examples. The fifth renovation system can be defined:

- Extension of the original facade on a separate construction connected to the existing building. Creating more open and expansive spaces without much work on the existing structure. The existing windows are mainly enlarged for glass doors.

The most promising retrofit options are the prefabricated module system and expansion due to shorter on-site production time, less labor-intensive (cost-demanding), quality control, occupied condition and increased space in the case of the expansion.

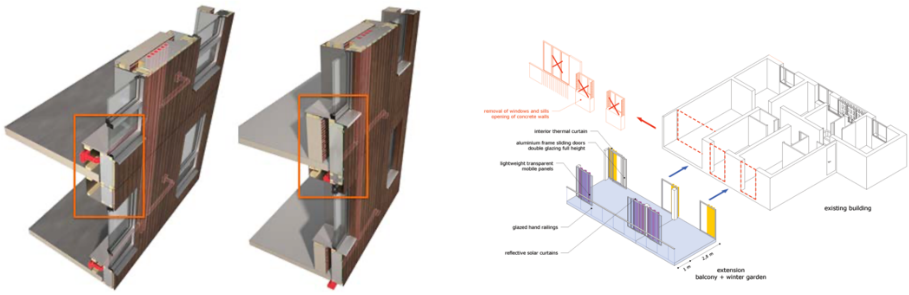


Figure 2. left: prefabricated module system (2nd skin), right: extension of the façade (grand parc Bordeaux) (Lacaton & Vassal architects, Frédéric Druot Architecture, Christophe Hutin Architecture)

An example of a prefabricated module system developed by BAM, ENECO, Rotterdam University of Applied Sciences, TU Delft is the 2nd skin project consisting of ventilation properties and improved thermal values. The main retrofit approach for the prefabricated panels is to identify similar buildings (facades, structures, etc.) and make their rehabilitation a priority (2nd skin, 2016). Modular mass production can therefore be applied for buildings with a standardized layout (apartment buildings). In this case, the facades and roofs are divided into several main panels, which are then installed on all buildings of the same type, which reduces the renovation time. The existing wall opening is demolished and a new window slides 'between' the existing space. The second-skin approach seems promising for renovation of post-war walkable apartments due to the streetscape regulations in the Netherlands; as a result, the existing structure and appearance of the building is preserved and the energy and climate performance are significantly improved from energy label F, to A or B. Label, ECC F: PE $\leq$ 280 kWh to ECC B: PE $\leq$ 120 or ECC A: PE $\leq$ 100 kWh, the criterion for a nearly zero-energy building (T. Kalamees, Kalle Kuusk, E. Arumägi, Üllar Alev, 2017). Energy label A or B depends on the maximum renovation costs that are available.

Renovation can take place in an occupied or unoccupied state. Vacancy results in residents having to live elsewhere for 1-2 years, as only less than 50% of residents return to their former renovated home (Reinhout Kleinhans, 2010). The great advantage of renovating vacant buildings is that the interior of the apartments can be tackled directly, leading to better indoor sound insulation and improvements to the wet areas that are usually poor in post-war homes. The exterior can be completely gutted leaving only the 'carcasses' of the building, which then forms a structured grid on which to place a new interior and facade. However, there is no one-size-fits-all compensation scheme.

Residents are sometimes entitled to a relocation allowance. This is a minimum of € 5,993 and only for renovations in which a tenant has to leave his home because it is not habitable (Rijksoverheid, 2021). The number of renovation projects for this approach has been brought in because of the freedom to work only with the existing concrete structure. The biggest problem with inhabited buildings is the limitation of renovation of facades and roofs. As soon as the tenant participates in the maintenance and improvement plan and continues to live in the house, they are eligible for an allowance for lost living pleasure of € 28.00 per day (price level March 2018) (Prowonen, 2019).

2.3 Which modular systems can be used for renovation of walk-up apartments?

The original meaning of 'module' (Latin word modulus) was a standard measure that ensured the correct proportions. German architect Walter Gropius created the modern concept of modular construction during the Bauhaus era (1919-1933), developing it further in the 1960s (Atli Magnus Seelow, 2018). At the time, building blocks were designed to a standard size and used prefabricated materials. The standardization process can significantly reduce costs by avoiding reinventing, enabling mass production, facilitating training, support, and troubleshooting. Simplicity mainly refers to the reduced structure in organizational management. '*In construction, modularity is often misunderstood*' (Thomas D. Miller & Per Elgård, 1998). Miller and Elgard define module, modularity and modularization. A module is an essential and self-contained functional unit in relation to the product of which it is part. It has standardized interfaces and interactions that enable the composition of products by combination'. Modularity is an attribute of a system related to structure and functionality. '*It often refers to the degree of flexibility where the components of a system can be separated and recombined. Modularization 'is the activity in which the structuring into modules takes place*' (Thomas D. Miller & Per Elgård, 1998). Modularity is usually a working scheme that can be found in floor plans or facades, as these determine the experience, appearance and climate performance of the building.

Modularity within existing renovation projects is not a much-discussed topic. This is closely related to the economic value of renovation. Only the extension on the roof may have been designed modular as an extension mostly only leans on the existing building. Mass production makes the economic value more feasible (Daniela Spirkova, Katarina Teplickam, Sona Hurna and Robert Janiss, 2021).

A new approach for modular renovation is the 'modular facade renovation with renewable energy technologies' (MFRRn). The MFRRn refers to the retrofit process in which thermal insulation, solar and wind harvesting technologies are integrated with the building exterior finish using a modular approach. The MFRRn must meet four basic aspects (four corners in Figure 3): work on existing buildings (retrofit), work on the facade (facade), modular approach (modularity) and integration of renewable energy technologies during retrofit (renewable energy) (Hu Du, Puxi Huang, Phillip Jones, 2019). The scope of MFRRn includes one type of facade, four types of retrofit purposes, two types of renewable sources, and all factors related to the module design, as illustrated in Figure 3. In order to reduce the retrofit time, the modules must include the HVAC ducts, heat distribution pipes, wiring (electricity, internet, sensors, TV, etc.) and renewable energy systems, if applicable. (Figure 3).

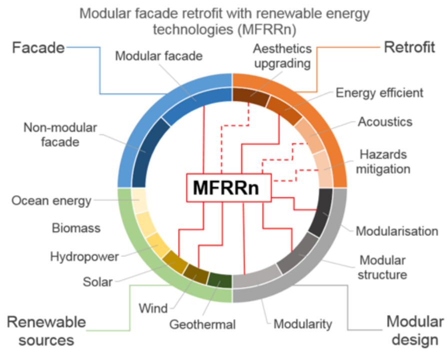


Figure 3. MFRRn principal scheme (Hu Du, Puxi Huang, Phillip Jones, 2019)

From a material point of view, the facade can be classified into metal, glass, concrete, masonry, plastic and wood (Thaleia Konstantinou, 2014). In terms of circularity, wood would be the main useful material, but for a fully assembled facade, minimal metal and glass should be added to match the architectural styles. The maximum building block is 12 meters long and 3 meters high, because otherwise special transport is required (Environment and Transport Inspectorate, 2016).

2.4 How are modular facade systems attached to buildings?

To see how facades are connected to each other in order to form an existing structure, we need to look at the evolution of the facade. This is influenced by the structure of the facade components and the difficulties with a modular facade. The evolution of the facade in a book by Knaack et al. (2004). A diagram of this evolution can be seen in figure 4.

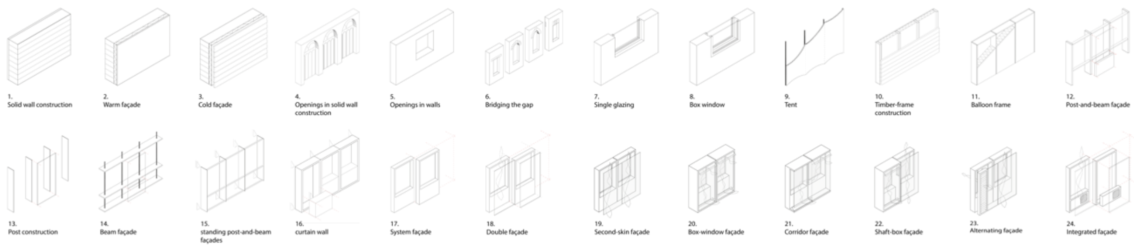


Figure 4. evolution of the façade (Reproduction from Knaack et al.)

‘*It can be said that the first modular facades expanded forward in the easiest way of timber frame construction. The modularity within the facade is mainly done by suspending elements on a separate structure or a two-layer element system where one element forms the structure and the other element is attached to the structure*’ (Kalle Kuusk, Peep Pihelo and Targo Kalamees, 2019).

The options for attaching a modular façade system to an existing façade are limited. Where there are 3 options and they have similar building elements as a separate facade element (IEA ECBCS Annex 50, 2011) (2nd SKIN, 2016) (Ligia Mihaela Moga, Adrian Bucur and Ionut Iancu, 2021):

1. Directly connected to the existing façade with the use of (concrete) anchors where vertical brackets are mounted. The brackets or hot-tip galvanized steel corner brackets support the prefabricated wooden panels.
2. Wooden vertical/horizontal structure is attached to the old façade, where the gaps are filled with ventilations ducts and insulation material. After which prefabricated panels are attached to the wooden beams, the windows are removed from the inside ones finished.
3. Separate (column) structure where the prefabricated panels are stacked. Metal anchors are attached to ensure that the panels stay in their dedicated place.

The directly connected and wooden vertical-horizontal construction has limitations because the existing construction should withstand the load of the connected panels. It is not recommended to hang the panels only at the bottom of the facade, as modules can show vertical deflections and settlements over time. The space between the carrying handles can be filled with light foam insulation. Another way to compensate for the surface slope is to use a filling layer, consisting of a light material (mineral wool) of 1-5 cm placed on the inside of the panel (Ligia Mihaela Moga, Adrian Bucur and Ionut Iancu, 2021).

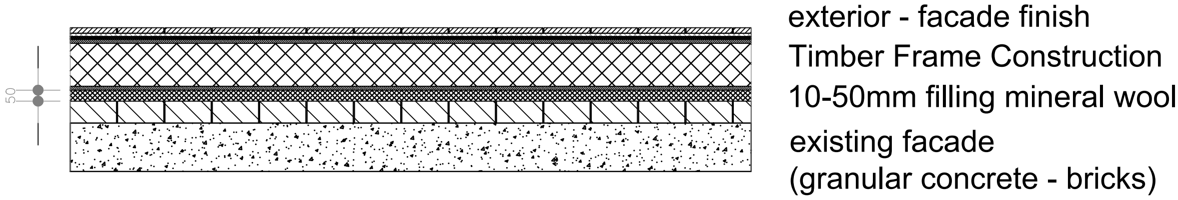


Figure 5. Section of the simplified prefabricated element.

In terms of construction time, the directly connected approach is the fastest (IEA ECBCS Annex 50, 2011). In the event of a building extension (grand parc Bordeaux, de la Tour Bois le Prêtre), this connection has a lot of similarities to the third approach, where the structure is separate but connected through metal anchors to ensure that the extensions stay in their dedicated place.

2.5 Are there existing computational projects with retrofitting of existing buildings?

'Algorithmic design does not eradicate differences but incorporates both computational complexity and creative use of computers. For architects, algorithmic design enables the role of the designer to shift from "architecture programming" to "programming architecture." Rather than investing in arrested conflicts, computational terms might be better exploited by this alternative choice' (Kostas Terzidis, 2006).

Limited information can be found on retrofitting by computational projects. However, the few examples that exist are nearly all constructed with the use of BIM (Building Information Model) (R. Hammond, N. O. Nawari, M. ASCE and B. Walters, 2014). BIM is a digital model of an existing and/or planned construction, made up of objects to which information is linked. In addition to the geometry and position of, for example, a wall in such a model, information can also be added such as the building material to be used (masonry or reinforced concrete), costs, the dimensions of a recess for a window frame and the course of piping (Ingibjörg Birna Kjartansdóttir, Stefan Mordue, Paweł Nowak, David Philp, Jónas Thór & Snæb jörnsson, 2017). This is usually done with software such as Revit or ArchiCAD. There are currently several developments within BIM. in these case studies nearly all include 3D laser scanning with lidar (V. Verma, R. Kumar, S. Hsu, 2006).
Which acquires a high density of point data in an accurate, fast way. The scanner can digitize all the 3D information concerned with a real world object such as buildings, trees and terrain down to millimeter detail Therefore, it can provide benefits for refurbishment process in regeneration in the built environment. A series of scans externally and internally allows an accurate 3D model of the building to be produced. This model can be sliced through different planes to produce accurate 2D plans and elevations. This novel technology improves the efficiency and quality of construction projects such as maintenance of buildings or groups of buildings that are going to be renovated for new services in the Built Environment (Yusuf Arayici, 2007) This is useful because most buildings are different and the buildings dimensions nearly always differ from the original building drawings (Engin Burak Anil, Pingbo Tang, Burcu Akinci, Daniel Huber, 2013).

Despite the increasing availability of measured laser scanning data and their widespread use, there is still the problem of rapid and correct numerical interpretation of results (Artur Janowski, Katarzyna Bobkowska, Jakub Szulwic. 2018). Therefore, the basis for dealing with minor variations between the built and designed dimensions is to implement dimensional and geometric variability through the use of comprehensive tolerance strategies (Yasaman Shahtaheri, Christopher Rausch, Jeffrey West, Carl Haas, Mohammad Nahangi, 2017).

Parametric design within architecture is defined by the following: (Emily Engle, Autodesk, 2020): *'1. Blending complexity and variety, thus rejecting homogenous utilitarianism 2. Shared priorities involving urbanism, interior design, an architectural wonder, and even fashion 3. The idea* *that all design elements are interdependent and adaptable 4. A skew towards computerized, algorithmic design processes or parametric design is a design process based on algorithms that creates rules for geometrical generation based on input from parameters that define them.'* With the surge of IT in recent years. Computers have reached enough power to calculate and produce large and complex geometrical forms based on that parametric input at ease (Jorge Tofalo, 2020). Where the parameters in this case will exist of dimensions of the existing buildings and latter parameters for the extensions/adaptations will be added.

There are only limited case studies when it comes to applying parametric values in the built environment. However, there is a clear trend of interest in the industry. No projects were found that use a computational approach to parameterize an existing group of buildings to adapt the buildings and use the parameters to cancel the differentiations between the buildings. This leads to a great opportunity within architectural computational research. Presumably, the interest in this parametric conversion for BIM and computational renovation projects will increase in the coming years" (Rafael Sacks, Mark Girolami, Ioannis Brilakis, 2020).

2.6 How can computational design methods support a generative renovation design for walk-up apartments?

Generative design is a method in which models are created and optimized by computer software. More specifically: generative design is an iterative design process that involves a program that generates a certain number of outputs that meet certain constraints, and a designer that fine-tunes the achievable region by selecting specific outputs or changing input values, ranges and distribution (Sivam Krish, 2011). Generative design has been around since 2009 but only started gaining popularity in 2017 (Arjen de Nobel, 2020). The reason for this is that it has been incorporated into the software from then on and in that way has become more accessible to a wider audience that supports generative design. As Grasshopper is a good example of this, the first release was in 2007, but was installed by default in Rhino 6.0.

In construction it can be used for optimization of geometry, daylight, buzz, visual and audio distraction and facade elements (Marc K. Howe, 2017) figure 6.

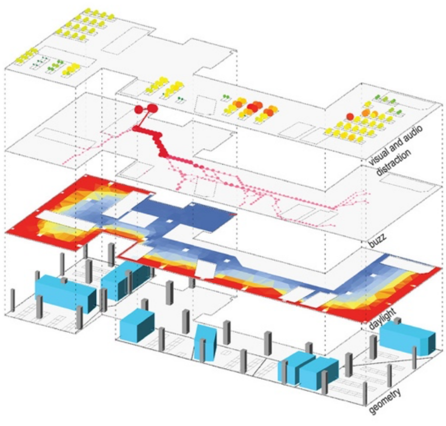


Figure 6. generative design principles (Marc K. Howe, 2017)

Generative design is a technology in which 3D models are created and optimized by computer software. Using generative design, optimization of these components can be generated as computers are very good at producing different iterations. When comparing these iterations, the best possible solution can be generated. When panels are modular, a generative design can indicate which panel is most optimal for which position. Which eventually can lead to mass production and optimization.

For renovation purposes generative design can help optimize the buildings. Most of the current structure of the building is already fixed. Optimization for daylight, buzz, visual and audio distortion, floor plan and façade elements are possible.

3. CONCLUSION

The study conducted research on how to improve the renovation process of walk-up apartment buildings through modular facades generated by computational design. The overall application on how to improve the renovation process of walk-up apartments would consist of the six sub questions. Several conclusions can be drawn.

First, there are 8 main building systems preferable for modular retrofitting through computational design: MUWI, Pronto, BMB, Korrelbeton, Vam, Rottinghuis Wilma and Welschen. Table 1 defines the 10 most used building systems for post-war walk-up apartments. When retrofitting a facade there are 4 main renovation techniques for walk-up apartments ((EA, ECBCS, 2011a): external composite insulation system, rear ventilated facade system, partly prefabricated façade system and prefabricated module system. Looking at the 'grand parc Bordeaux' and 'de la Tour Bois le Prêtre' there is a renovation technique which doesn't directly change the façade as an element but extends on it in the form of a self-supporting balcony. Therefore, the most promising retrofit options are the prefabricated module system and its expansion is due to shorter on-site production time, less labor-intensive (cost-demanding), quality control, occupied condition and increased space in the case of the expansion.

Thirdly, A module is an essential and self-contained functional unit in relation to the product of which it is part. It has standardized interfaces and interactions that enable the composition of products by combination. Thereafter, modular facade panels are connected which can be done through; 1. Directly connected to the existing façade with the use of (concrete) anchors where vertical brackets are mounted. 2. A wooden vertical/horizontal structure is attached to the old façade 3. Separate (column) structure where the prefabricated panels are stacked.

Limited knowledge can be found on research done to retrofitting by computational projects, however, the few examples that exist are nearly all constructed with the use of BIM (Building Information Model). Parametric design is a design process based on algorithms that creates rules for geometrical generation based on input from parameters that define them. No projects were found that use a parametric computational approach to modify an existing group of buildings and use the parametric to define the differentiations between the buildings.

Generative design can help in retrofitting projects for optimization: daylight, buzz, visual and audio distortion, floor plan and façade elements. Generative design is an iterative design process that involves a program that generates a certain number of outputs that meet certain constraints, and a designer that fine-tunes the achievable region by selecting specific outputs or changing input values, ranges and distribution (Sivam Krish, 2011).

The research question: how can the renovation process of walk-up apartments be improved by using modular facade components generated by computational design? can be answered as follows: Renovation can be improved by using modular MFRRn prefabricated panels or extension of the original building, connected directly to the original façade or connected but supported by its own foundation. Computationally developed using a parametric script that implements generative design for the best possible result. Preferably one of the following building systems applied after the second world war for walk-up apartments: MUWI, Pronto, BMB, Korrelbeton, Vam, Rottinghuis, Wilma or Welschen.

This research has a number of limitations. The amount of case studies of which archived documents are available is limited, especially from the post war period. Research to recycling concrete and the applicability of a second facade have not been performed but would be a valuable addition in further research.

4. DECLARATION OF COMPETING INTEREST

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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