MORE-CONNECT (ARCHITECTURAL) DESIGN GUIDELINES

D 3.6 Platforms for (aesthetic) configurations and user/owner options within the basic elements configuration and within performance criteria

MORE-CONNECT, November 2018, J.A.W.H. van Oorschot, MSc., ed.

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D 3.6 PLATFORMS FOR (AESTHETIC) CONFIGURATIONS AND USER/OWNER OPTIONS WITHIN THE BASIC ELEMENTS CONFIGURATION AND WITHIN PERFORMANCE CRITERIA

J.A.W.H. van Oorschot, MSc., ed.

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CHAPTER 1: SHORT INTRODUCTION

1.1 Aim of the report

To improve the current building stock towards near zero energy buildings, retrofitting surpassed the level of the improvement of isolated building components, such as roofs, façades or heating systems. This approach often results in inefficient solutions. Optimal results cannot be achieved by single renovation measures and even worse new problems could arise, including local condensation or overheating.
MORE-CONNECT aims to develop and demonstrate an innovative modular building renovation concept for housing across different EU geo-clusters. The concept is based on largely standardised façade and roof systems that are suitable for prefabrication. The highly insulated new building envelope includes the integration of HVAC systems among other technologies (like PV).
This report links to Work package 3: System integration of the H2020 project MORE-CONNECT. One of the key issues related to this work package is the development of design rules or guidelines which support the design process of prefabricated modular façade elements. As have been emphasised in multiple innovation projects in this field, like ANNEX 50, ProGETonE and MORE-CONNECT, the lack of knowledge on innovative deep retrofit design methodologies, including the adoption of prefabricated systems, is hindering the wider market adoption of such highly promising technological solution.

Problem definition:

The lack of knowledge on innovative deep retrofit design methodologies, including the adoption of prefabricated systems, is hindering the wider market adoption of such highly promising technological solutions.

Therefore this reports aims to outline the design guidelines for modular prefabricated façade. These design guidelines in particular should take into account the needs of the client(s) and/or occupants. In contrast, industry is looking for opportunities to create a market out of single demonstration projects and therefore aiming at replicability and industrialization. Thus, the design guidelines should balance industrialization and customization in terms of mass-customization. Subsequently, based on these design guidelines, encapsulated in a morphological design matrix, a MORE-CONNECT DESIGN TOOL will be developed.

Aim of the project:

The aim of this project encompasses the development of guidelines for the design of prefabricated façade modules taking into account user/owner (aesthetic) options within the basic elements configuration and within performance criteria linked to (n)ZEB retrofitting of existing housing.

The following seven steps are characteristic for deep retrofitting toward zero energy housing (ANNEX 50; Van Oorschot et al., 2016):

1. Market potential evaluation and preliminary building analysis

Preliminary assessment of the potential of the existing property taking into account multiple options ranging from value retention, part(ial) renovation, comprehensive renovation or a new building replacement. Investors could select from the following options:

1) suspend investment in favour of the status quo;
2) invest to preserve the property, i.e. anyway renovations (for a period up to 10 years);
3) invest to renovate the property (for a period up to 25 years);
4) invest to transform the property according the principles of a near energy zero build environment (for a period up to 50 years);
5) invest to replace the property, or;
6) to sell the property.

2. Needs evaluation

Identifying the needs and parameters of the most important stakeholders and multipliers of advanced retrofit: owners, planners, constructors and public authorities

3. Building analysis

Detailed analysis of the built structure and its relevant system components in order to identify retrofit options

4. **Target agreement**
Combining retrofit options to provide a building strategy with high added value over the entire life cycle.
5. **Planning & design**
Planning and design of the project, including the design of prefabricated façade modules
6. **Execution**
During this step the project will be realized on site including mounting the prefabricated façade modules.
7. **Target Effectiveness Evaluation**
Evaluation of reaching objectives during at least one year of operation after work completion.

Following step I to IV, it first has to be decided whether or not to invest in deep retrofitting from a strategic real estate policy perspective (Annex 50, Van Oorschot et al., 2016). Subsequently, not only need to be evaluated what the needs are of the involved stakeholders, in particular occupants, but it also need to be determined or the building meet the requirements to be renovated according the principles of modular façade elements (MORE-CONNECT WP 3.1; Annex 50). Finally, after the concept and design requirements are determined the planning and realization phase will implement the deep retrofitting concept into practice. Thus, during these preliminary steps it need to be decided which approach will be adopted and implemented in the project (steps V and VI). Accordingly, during the realization phase the retrofitting solution will be designed and engineered. This report addresses the design guidelines for the of prefabricated renovation modules, during step 6. It also presents the MORE-CONNECT DESIGN TOOL which is based on the design guidelines. The other steps fall beyond the scope of this report. This publication in particular builds upon the insights from previous conducted research and development projects related to deep renovation, including:

- ANNEX 50
- Bouwhulpgroep
- 2D gevel

See also:
www.empa-ren.ch/A50.htm
www.ecbcs.org/annexes/annex50.htm
https://www.progetone.eu/project/
http://www.more-connect.eu/

1.2 Methodology

Two methodologies have been applied to develop this report. First, desk research have been conducted to review previous experiences with respect to the design of prefabricated façade modules. Second, building upon an innovative design methods design guidelines are developed based on the insights developed in the MORE-CONNECT case projects. Therefore this reports builds upon an design approach developed by Van den Kroonenberg (Siers, 2004; www.bouwnext.nl).

1.3 Structure of the report

This report is structured as follows. In the next chapter the theoretical background of modularity in the housing sector will be discussed as the theoretical cornerstones of prefabricated façade modules. Chapter 2 discusses the design requirements and basic structure of the façade modules. The subsequent chapter addresses the design guidelines of façade modules. Chapter 4 presents the conclusions of this report.

CHAPTER 2: THEORETICAL BACKGROUND – MODULARITY IN THE HOUSING SECTOR

Modern methods of construction (MMC) are innovative building practices that aim to improve the quality of construction assets. In many cases, they displace work from the construction site to the factory. It faster construction time on site and improves product's life performance; it reduces defects in the construction, waste of materials, number of workers on site, risks and construction costs (Pan, Gibb, & Dainty, 2007). MMC comprises modular building, preassembly, prefabrication, offsite production (OSP), offsite manufacturing, industrialized building, and other innovative construction practices on and off site (Rahman, 2013).

Modularity is a technique which builds larger systems by combining smaller sub-systems. A modular innovation is a significant improvement (or even a new concept) within a specific area, which does not require changes in other components or systems (Henderson & Clark, 1990). Modular systems are designed independently but still function as an integrated whole. By breaking up products into sub-systems or modules, designers, producers and users have developed enormous flexibility to intervene in the process of product development. Modularity in design encourages competition, different agents can develop a product or sub-system that can be coupled to the main system. In addition, same products can be developed in parallel and a bigger rate of innovation can be expected from it (Baldwin & Clark, 2003). When modularity is just starting to be adopted and implemented in a company, it requires more coordination between developers of the product to set the interfaces between modules. Designers must work in collaboration and have general knowledge of the overall product to set stable design rules that function as a solid base for the development of the modular product.

2.1 Characteristics and design rules of product modularity

Modular architecture is characterized by having a one-to-one mapping from functional elements in the function structure to the physical components of the product, and specifies no tied interfaces between components. Modular innovation allows a straightforward implementation, with no changes in other systems. Responsibilities and liabilities are easy to be allocated since they are coupled to the product developer.
In an ideal and completely modular architecture, a modular component of the architecture system should be able to be replaced without affecting other modules of the system or its overall performance. Modularity is based on the principle of interdependence of modules with independence across them. Design rules clarify the interactions across a product's sub-systems, reduce component specificity, and provide a form of embedded control that reduces the need for overt hierarchical control or ongoing communication during concurrent improvements of individual subsystems. Product architecture, interfaces, integration protocols and testing standards are the design rules' categories upon which decisions are made to conceive new modular products (Baldwin & Clark, 2000)

Box 1: Key challenge of modularity: primitive learning processes about the design rules

Thorough knowledge of the construction of the existing housing is key to the development of modular deep-retrofitting solutions. Especially while retrofitting appears to be cyclical. Every ten to fifteen years retrofitting need to be 'reinvented' for the housing being erected or adjusted. However, the residential sector has a poor history concerning systematic data collection about the existing housing stock. Knowledge about possibilities, constraints and bottlenecks of the existing building is poorly documented, especially when it comes to additions.
Nevertheless, the first generation two dimensional solutions of façade renovation have been developed decades ago. However, theoretically, one knows how to do it, but the performance is eventually disturbed by deviations that have not been taken into account beforehand: size tolerances, impact of demolition and corners (3D). The negative effects of deviations come to light when they need to be corrected during the execution and normally result in additional work and cost and loss of quality. When choosing a 'seal form' (airtightness), the existing building structure in relation to the assembly principle need to be considered with respect to the method of insulating and 'sealing' and the manner of execution. There must be a proper alignment of the requirements.
At present, working with the existing building is an ongoing exploration journey through the history of construction. Due to the lack of documentation, partly due to the lack of continuity in practice, every individual and every construction must build up their expertise. Knowledge development is thus a very primitive learning process and a key bottleneck of the advancement of deep retrofitting.

Box 2: Example of (successful) modular consumer durables

O-bag [1]

[1] http://www.obagshop.nl/

2.2 Modularity in the housing sector

Modularity is a MMC's that aims to improve quality and efficiency in the construction sector. In this sector, there is a recurring dilemma involving the need of having standard products to increase quality and the need of flexible customized products to satisfy the needs of the clients. Customers value distinctiveness and customization of their property, while construction companies look for solutions that reduce costs and delivery time and an increase of product quality. Baldwin and Clark (2000) present modularization as one way of mitigating client demands for variation and supplier requirements on repetitiveness.

BOX 3: Example modular housing components

Prefab box-in-box bathroom pod - Faay Prefab Products [1]

Climate box – Nathan [2]

Plusdak – Stafier Solar Systems [3]

[1] https://www.faayprefabproducts.nl/prefab-badkamers/
[2] http://www.nathanprojects.nl/projecten/woningbouw/nul-op-de-meter-woningen-met-nathan-energiemodule/
[3] http://www.plusdak.nl/

2.3 Modularity and deep retrofitting

Currently, the Netherlands counts about 7 million dwelling; Europe about 250 million. Deep-retrofitting the Europe housing stock could benefit from a modularity approach for a variety of reasons.

1) Environmental impact

In 2015 the household sector was the second largest producer of Greenhouse Gas emissions in Europe (Eurostat, 2016). The European Commission is therefore looking at costs-efficient ways to make European economy more climate friendly and less energy-consuming. Emissions from houses can almost completely be cut by making use of passive technologies, refurbishing old buildings and substituting fossil fuels with renewable fuels (Directive2002/91/EC, 2002). In 2010 the Energy Performance of Buildings Directive (EPBD) set a directive (Directive2002/91/EC, 2002) to improve the energy efficiency of EU buildings. Energy performance improvement can be reached by implementing innovative nZEB retrofit solutions by which an outdated house stock can be upgraded and energy consumption can be reduced (van Oorschot, Hofman, & Halman, 2016).

2) Viable business case (mass-customization)

There are already several deep-retrofitting concepts available in the market, most of which are based on a so-called 'one-time-good' approach: the house is brought with one intervention from the current level toward the level of new build or even zero energy housing. From a (n)ZEB policy perspective this an excellent starting point, however the question is whether this is the most cost effective way. Is there enough attention for the comfort of living, or should the resident change his or her behaviour? In addition, in practice, the most important question: are these deep-retrofitting concepts affordable? As a result the return on investment takes multiple years up to 50 year. This limits large scale application of such concepts.

3) Shortage craftsmen

A major problem in the long term will be the available working force capacity for total residential construction sector. The increase in maintenance and renovation leads to two major problems in the current mode of production:

- An unfavourable cost-benefit ratio (too expensive in relation to new construction);
- Traditional approaches are labour intensive resulting and within a market characterised by a shortage of craftsmen this could become problematic in terms of production.

4) Changing market demand

Clients demand has changed over time in particular with respect to the level of customization in housing design and comfort. First, professional clients, building owners and housing associations, transfer risks and tasks to the industry and demand a smoothly organized and speedy process. They allow variation in design (occupants are granted a certain level of customization), but within a consistent image quality, because of the value of their possession over time. Next, end users (occupants) demand more comfort at a better value for money, more freedom of choice, more individual appearance and less inconvenience during the retrofitting process. Finally, society demands more sustainability, safety and health.

Taken together, he advantages of a modular deep-retrofitting approach encompass (see also Annex 50, Plug&play; Bouwhulpgroep:

1. Product oriented instead of the traditional project-based approach.
2. An improved cost-quality ratio. Due to the limited productivity development in retrofitting and the impact of (poor) labour productivity, retrofitting is becoming increasingly expensive.
3. Improved energy efficiency resulting in a low(er) environmental impact. The quality additions in the existing building must be at least energy zero.
4. High level of customization. Individuality is inextricably linked to (appropriate) customization.
5. Limitation of risks. Intervention in existing homes is always linked to short and long term risks. In the solution, this aspect will require extra attention, establishing a clear relationship between existing and added quality.

By decomposing housing into different modules, the existing housing stock could be structured in a different way. In contrast to structuring the building stock into typologies based on layout and year of construction, housing could also be structured based on the modules it is composed of. For example, a roof can be the same module for different types of dwellings at different geographic locations. The challenge will be not to view a dwelling as a 'off' product, but much more as a composition of various components which change over time (http://www.bestaandewoningbouw.nl/de-familie-doorzon/).

If dwellings and the deep-retrofitting solution are considered from a modularity perspective, i.e. an aggregation of 'loosely coupled' products and materials, the sector and the market alike could benefit from mass-customized deep-retrofitting solutions of high quality. In this respect modularity combines standardization and customization. First, modules can be replicated in subsequent projects and stimulate learning practises. Next, occupants could choose between multiple suppliers and customize the modules to their needs and wishes (based on a preselection of alternatives). This makes it possible to achieve better quality at a low price (scale benefits) during construction as well as adjustment over time.
The carriers of such standardization are the modules which comprise a single dwelling or apartment block. A module is defined as a composition of related building components and materials that provide a utility function - of a building or single dwelling (such as roof, facade, home interior, etc.). Housing typically consist of the following basic modules which need to be considered to modularize deep retrofitting (Liebregts and Van Bergen, 2010; Verbouwkompas, 2015; Energiesprong, 2016):

1. Foundation
2. Façade (figure 3)
3. Roof structure (figure 4)
4. Layout (floorplan)
5. Extensions
6. Built-in structures (kitchen, bathroom, toilet, staircase, meter cabinet)
7. Energy installation (heat pump, photovoltaics)

BOX 4: Housing modules – definition

A module is defined as a composition of related building components and materials that provide a utility function - of a building or single dwelling. This development began with the kitchen and today have been copied by other module suppliers (Box 3).

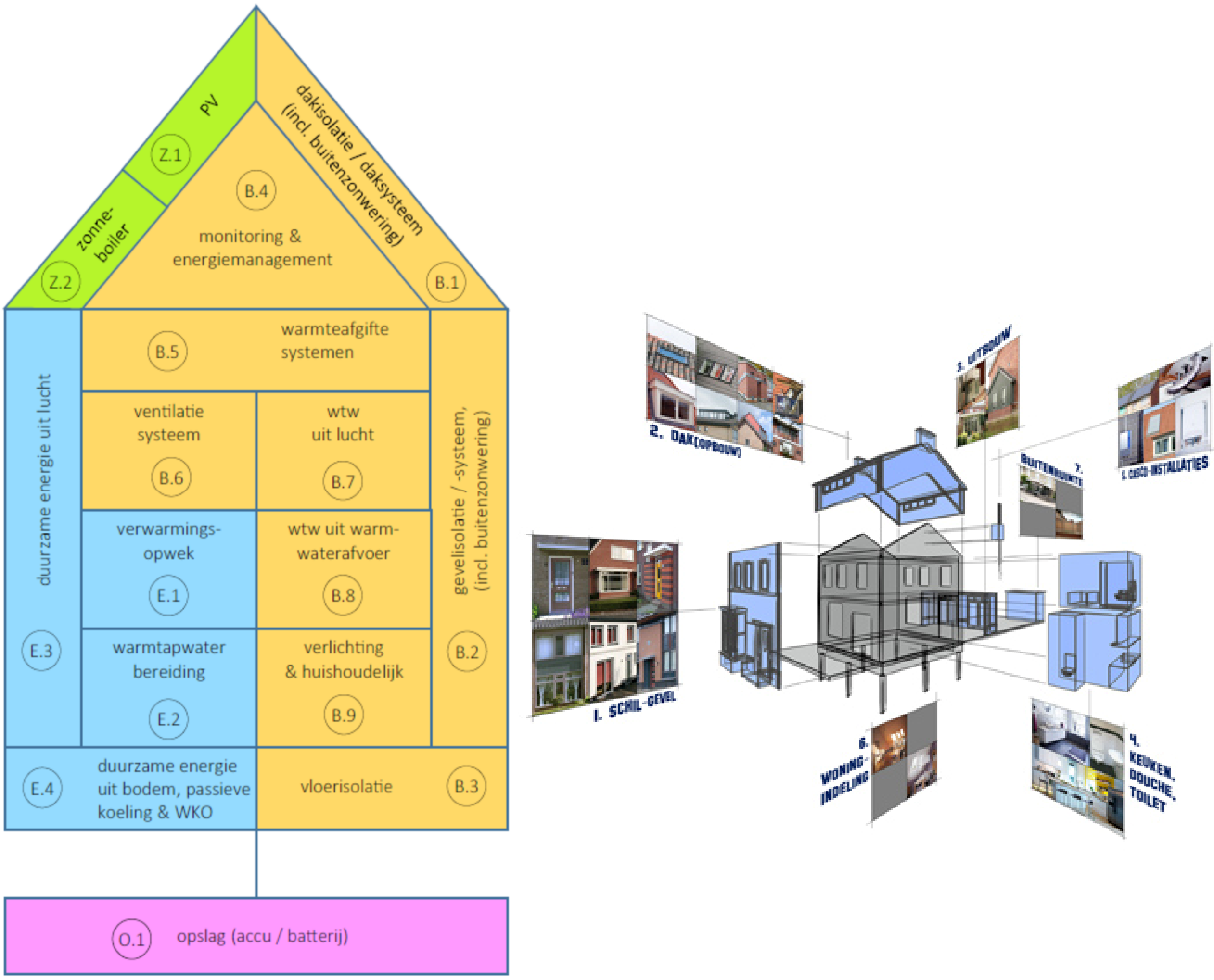
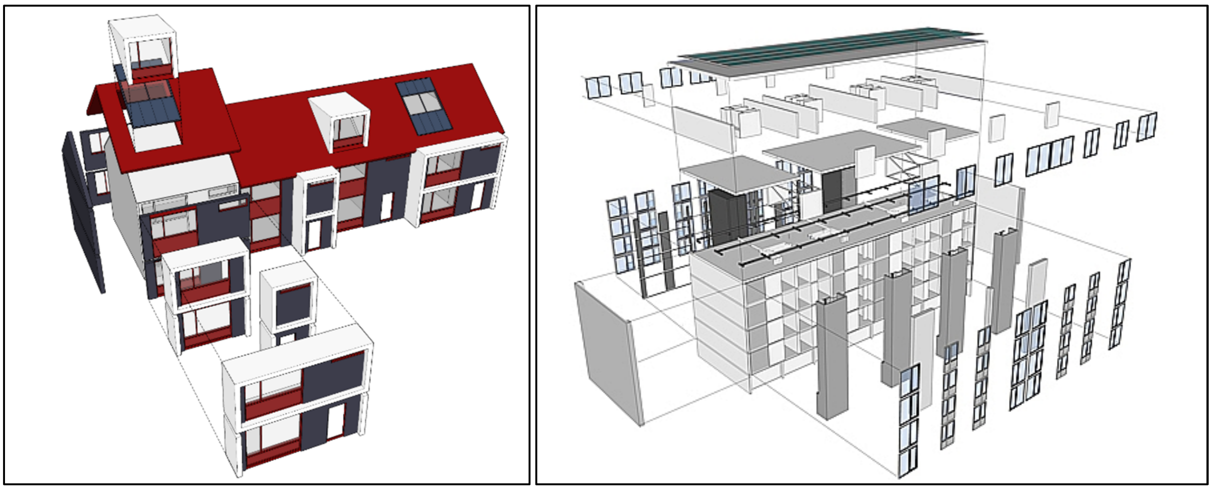


Figure 1: Modularity; key components when considering deep retrofitting (adopted from Energiesprong, 2016)



Single family housing [1]

Apartment building [2]

Figure 2: Project based design alternatives from a modular deep-retrofitting perspective

[1] http://www.hollands-ontwerp.nl/vandaag-experiment-morgen-bewezen-techniek/#more-1127

[2] http://www.duurzaaminstaal.nl/p/587/endis-portiekflat-renovatie.html

Figure 3: Design alternatives of the roof subsystems. These typologies shape the market of facade-modules (adopted from: http://www.bouwhulparchief.nl/onderzoek/eindhoven_alliantiegevelbeam.php)

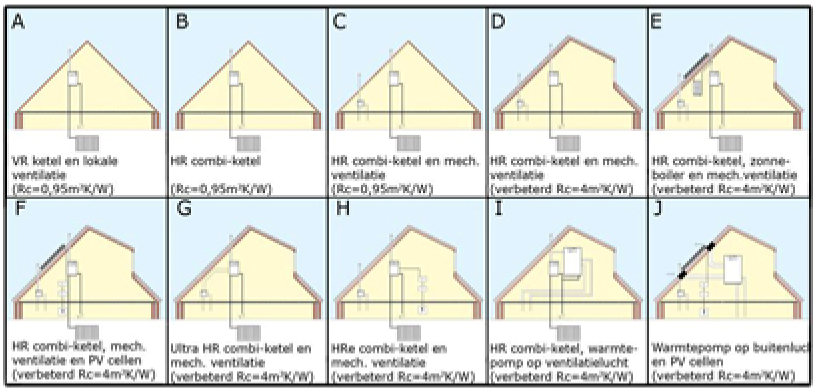


Figure 4: Design alternatives of the roof subsystems. These typologies shape the market of roof-modules (adopted from: http://www.bouwhulparchief.nl/onderzoek/eindhoven_alliantiegevelbeam.php).

Box 5: Deep retrofitting costs

Modular deep-retrofitting practices lends itself to optimizing production (cost). Extensive prefabrication and ‘dry’ assembly at the building site contributes to cost optimization. An indication of the building costs:

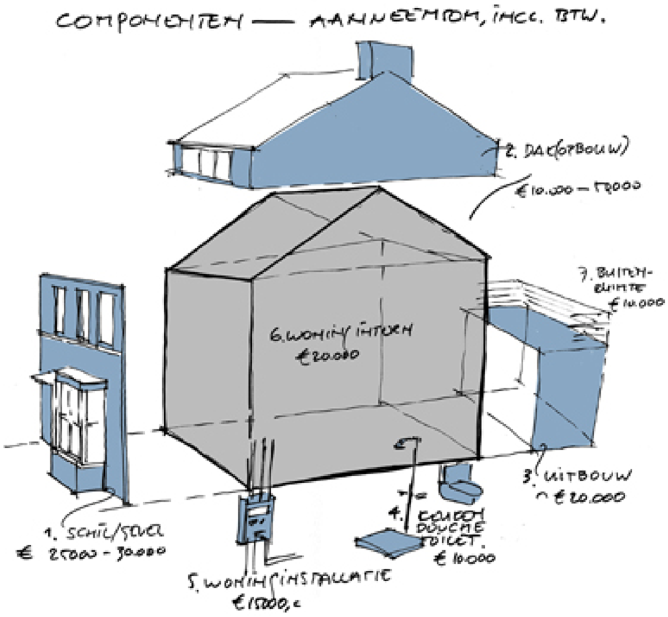


Table 5.1: Housing transformation investments versus new-build investments (demolition cost and land cost not included)

Concept characteristics	First generation deep-retrofitting projects in The Netherlands (2007)	Optimization (2016)	New-build
Energy label (improvement)	G/F --> A++	G/F --> ZEB	A++
€/dwelling * (case study)	€90,000-120.000,-	€65,000-85.000,-	€115,000,-
€/dwelling * (reference)	€65,000-85,000,-	€45,000-65,000,-	€81,000 (average Dutch for rent market)

***labour and materials; new build consists about 40% of labour costs. In contrast, renovation consists about 60% of labour costs. Optimazation results from diminishing labour on-site (by 10-20%) as result of standardization (http://www.bestaandewoningbouw.nl/met-component-renovatie-30-goedkoper/)**

Kosten opbouw renovatie versus nieuwbouw

	Arbeid		Materiaal		Totaal	
Nieuwbouw	€ 46.000	100	€ 69.000	100	115000	100
Hoog niveau renovatie	€ 78.000	170	€ 52.000	75	130000	113
Component renovatie traditioneel	€ 78.000	170	€ 52.000	75	130000	113
Component renovatie geoptimaliseerd	€ 52.000	113	€ 48.000	70	100000	87

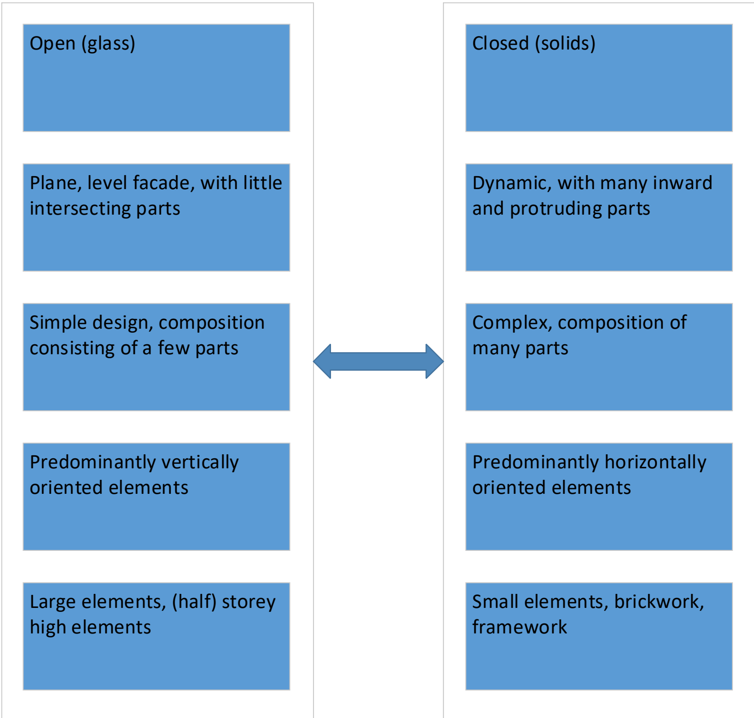
Kosten ex BTW

CHAPTER 3: DESIGN REQUIREMENTS AND BASIC STRUCTURE OF THE MODULE

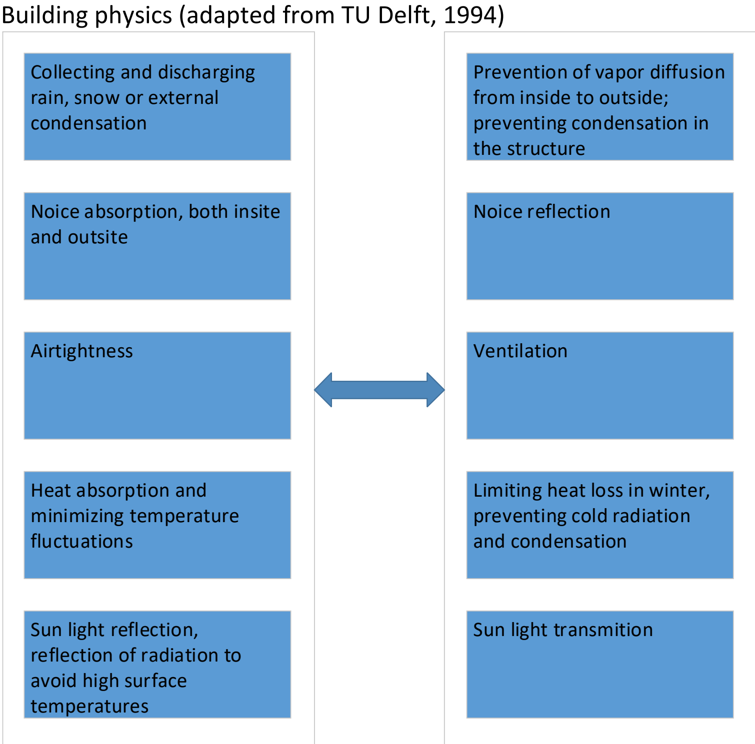
3.1 Design requirements

The design of the building envelope, in particular the façade, needs to meet several performance criteria. besides that it need to be architectural appealing. These criteria relate to the physical, structural performance of the building envelope (TU Delft, 1994).

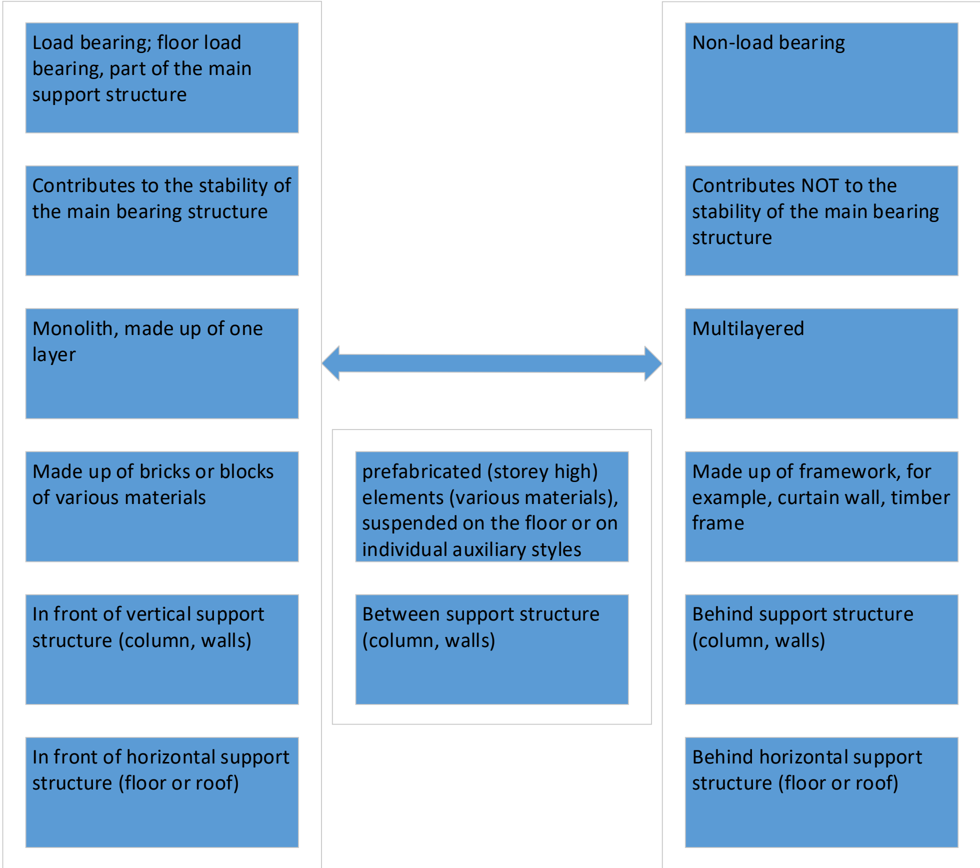
Architectural (adapted from TU Delft, 1994)



Building physics (adapted from TU Delft, 1994)



Structural (adapted from TU Delft, 1994)



The flexibility of the MORE-CONNECT façade modules allows it application on a wide array of housing typologies distinguishing between archetypes, thermal properties, geo-localization, and energy systems. Taking into account project(-site) based boundary conditions, the design of the modules need to take into account the following basic technical requirements:

- Energy sources
  - Various combinations of electricity, district heating, natural gas, biomass boiler;
  - Presence of active production from RES including PV on roofs, additional façade installation and domestic hot water (DMW) from solar panels.
- Heating system
  - High-efficiency heat pumps, inclusion of heat recovery systems
  - Possible source of heat or electricity for circulating DHW
- Ventilation system
  - Mechanical ventilation with heat recovery
  - Requirements on air ducts in modules
  - Need for HVAC modules (possible locations: cellar / loft / outside)
  - Need for indoor air ducts for exhaust air – indoor modules needed
- Smart connectors
  - Mechanical smart connectors (for structural support and joints)
  - Air ducts
  - Heating pipes
  - Low voltage for controls of electricity loads
  - PV wiring
- Smart building management, monitoring, and control
  - Temperature
  - Humidity
  - CO2
  - Heat flows
  - Individual room control

Besides these technical requirements, additional project requirements are suggested related to a range of items which link to the different ‘functionalities’. These criteria include or relate to (Adopted from Geavanceerde plug&play gevel 2D voor renovatie, report BouwhulpGroep and Cauberg-Huygen):

1. Social security within the building and immediate environment
2. Burglary safety
3. Accessibility of the building and immediate environment
4. Accessibility of the housing unit including the accessibility of single spaces within
5. Accessibility home appliances and service installations (concerning maintenance of specific components)
6. State of maintenance building and immediate environment
7. Building identity
8. Identity of home appliances and finishing
9. Luxury appearance of the building
10. Luxury appearance of home appliances and finishes
11. Size and spaciousness of housing units
12. Flexibility
13. Ease of use of home appliances and service installations
14. Healthy indoor climate
15. Comfortable indoor climate (thermal / acoustic).

Box 6: generalized list of requirements

The development of the prefabricated façade modules is based on the premise that the proposed solution must meet some common design targets, including (Progetone, MORE-CONNECT wp2): • Be adjustable to fulfill the needs in different climatic and seismic conditions target typologies • Be variable in its thermal properties, providing various levels of refurbished buildings' energy • performance • Enable variability in design of external surfaces • Enable mounting/anchoring of outdoor extensions such as balconies and shading devices according • to the architectural requirements • Ensure compatibility for reinforcing the exist. structure for seismic stability • Integrate air ducts for HVAC systems, piping for heat distribution, wiring (electricity, internet, • sensors, TV etc.) • Integrate renewable energy systems • Be compatible with alternative thermal insulation systems and • Fit for all situations where the renovation project requires complete, partial or no removal of existing structures. • Enable fast installation without need of scaffolding • Be based on modules that are transportable with standard means of transport

Prefabricated facade modules bring about innovation in deep retrofit solutions, compared to traditional refurbishing techniques, technologies, and practices. As each building has intrinsic boundary conditions and differences in technological requirements, so are the demands of the building users, i.e. in terms of the need for building extensions, variability in comfort requirements, in a way to meet legislation regulations. Several key innovation aspects (Progetone):

- Rapid improvement of building energy performance and users' living comfort: A combination of high-performing technologies are embodied in the multifunctional modules, including thick layers of thermal (super)insulation materials, new low-U-value windows, use of renewable energy sources, HVAC and energy systems, as well as advanced control systems, etc.
- Minimal intervention (low-intrusiveness) to users' life during the renovation: The renovation process is faster compared to traditional solutions since as much technology is embedded in the modules and is mounted on site. Key elements are installed over the exterior walls (when existing envelope is kept), so low-intrusiveness also due to the main external character of the intervention.
- Extension of the building area: When there is a sufficient space around the building, prefabricated modular systems can enlarge the usable area of the housing unit. It can be made either by small additional structures such as balconies (see the P2Endure project) or by larger glazed winter gardens. Another way is the extension to the loft or upon the roof of the existing building, or providing an opportunity to customize the flat the user's way (see the MORE-CONNECT project).
- Passive strategies: The renovation process can include the adoption of extension of building area with modular systems to significantly reduce the need for mechanical systems. Modular glass façade additions around the perimeter of the building can enhance the overall performance (energy demand and comfort) of an existing building effectively, by means the creation of buffer spaces. Buffer spaces allow the modulation of the indoor temperature, taking advantage of the radiative temperature difference between the building environment and the sky temperature during the summer and winter season.

  Alternative passive strategies for deep retrofit, including the enhancement of both energy performance and comfort for the users, entail the prevention of solar radiation from reaching the building and its interior, for the avoidance of indoor overheating and glare conditions. This can be achieved by including obstacles such as shading devices within the modular elements for deep retrofit or directly manipulating the solar-optical properties of glazed surfaces (high reflectivity, thermochromic, electrochromic, holographic glasses) used for the prefabricated components.
- Flexible architectural design: The renovation process becomes flexible enough to cope with all set of challenges from boundary conditions and needs from the building stakeholders, allowing variable configuration of the diverse technologies, including:

- Joints: Thinking of apartment houses, panels cannot be manufactured in size of the whole façade, therefore they have to be connected to seal the façade and to ensure the mechanical cooperation of the whole structure. The flexible design can also enable joint in an inner or outer corner of the building.
- A variety of external surfaces: The designed panel can allow the execution of any common type of façade finishing (thin plaster, wooden cladding, cement boards, etc.).
- The combination of external surfaces: The designed panel can allow the combination with other types of façade renovation systems, such External Thermal Insulation Composite System (ETICS) for instance in the basement or at one facade.

From previous projects some various lessons have been learned concerning the overall success of deep-retrofitting with prefabricated modules. This has resulted in several implications for the design of the modules (http://www.hollands-ontwerp.nl/prijsvraag-hollands-ontwerp-award-2012/; Liebregts & Van Bergen, 2011):

Smart and fast

During the construction work, restraint of nuisance and the good cost-quality ratio is of utmost importance. Construction work should be based on the principle 'done while you wait'. Furthermore, construction work should be completed in time according planning.

Additional comfort: insulation and safety

Proper comfort and safety are quality aspects that change over time and are partly influenced by technical developments and capabilities. Combining deep-retrofitting with additional comfort measures enhances the future value of the property.

Architectural appearance

The architectural appearance has a positive effect on the acceptance of the deep retrofitting; i.e. technical limitations should not affect the architectural performance of the design.

Performance guarantees

While deep-retrotting is costly on the one hand and often involves technologies which building owners and occupants are not acquainted to on the other hand, performance guarantees are essential to get deep retrofitting adopted. Next, services with respect to maintenance could contribute to the susceptibility of the deep-retrofitting solution.

Customer service 24 hours

In addition to maintenance service, customer service can also be offered as a 24-hour service (today this already offered to the market for specific component including the glass service and the gas-boiler service).

Table 1: Nine performance fields deep-retrofitting (http://www.hollands-ontwerp.nl/prijsvraag-hollands-ontwerp-award-2012/; Liebregts & Van Bergen, 2011)

		Concept / vision		
		Smart & Fast: The extent to which the existing techniques for improving the cost-quality ratio are used	**Integral:** The extent to which the intervention addresses a variety market needs	**Affordability**: Mass-customization, balancing mass production principles and customization
Aspects of deep-retrofitting	**Product: quality improvement of the building.**	**Customization:**	**Comfort, space and (aesthetic) appearance:**	**Reduction:**
		To what extend are individual occupant needs accounted for? Which alternatives / options to select from?	Which performance criteria are taken into account?	To what extend is the environmental impact (energy reduction) of the building reduced?
				Standard modules:
				To what extend are standardized modules/ components applied (cost reduction)?
		Level of prefabrication:	**Synergy (1+1=3):**	**Reduction exploitation costs:**
		To what extend is on-site labour reduced?	To what extend does the project benefit from a holistic approach with respect to the overall project performance?	To what extend are the exploitation costs reduced?
	Process: quality insurance.	**Reduction construction time:**	**Environmental impact**	**Standardization:**
		To what extend is the construction time reduced in contrast to a more traditional project approach?	What is the environmental impact (in contrast to a more traditional project approach)?	What is the level of standardization within the project?
		Reduction hindrance:	**TCO Total Cost of Ownership:**	
		To what extend does the project hinder the involved occupants (in contrast to a more traditional project approach)?	What is the effect on the 'total cost of ownership'?	
		Overhead costs:	**Client orientation:**	**Project stages:**
		To what extend are the project specific costs reduced (relocation, allowances)?	To what extend does the project build upon the principles a 'client centric' approach?	During which stages of the project are considerable cost reductions achieved?
	Collaboration project partners	**Reduction project preparation:**	**Quality guarantees**	**Finance & affordability**
		To what extend is the project preparation time reduced by improved collaboration between project partners?	Do the project partners guarantee long term quality performance?	How does the business case look like? Which financial incentives are applied to ensure affordability?
		Reduction overhead costs:	**Knowledge**	**Innovation cost/benefit ratio**
		To what extend are the project overhead costs reduced as a result from improved collaboration?	Which tools are used to ensure knowledge transition from project to project?	Which innovations are introduced to improve cost/benefit ratio of the deep-retrofitting approach?

3.2 Basic structure of the module

Depending on the building typology and characteristics diverse retrofit strategies for the design of the basic modules can be applied (MORE-CONNECT WP2.2):

- Complete removal of the facade and/or roof and full replacement;
- Partial removal;
- No removal of the façade and/or roof and addition of prefab elements.

Given the variability in external structures of the building types taken into account and the requirement of integration of air ducts, wiring and piping into the external modules, design strategies must consider the different possible ways of mounting of the prefabricated modules. Also, the geometry of the wall modules and its relative position depends on the following key questions:

1. Can the original external wall be removed?
2. Is there present any structural vertical element to enable connection of the piping, wiring and air ducts close to the floor structure?
3. Can the window openings be extended (depending on the material and structure of the walls)?

The design choices for the basic modular panels and elements are the result of a decision-making process that takes systematic account of the boundary conditions of the building, and of the architectural, normative and comfort requirements of the building stakeholders.

There are two different approaches for retrofit module design (Annex 50). The first approach includes a totally prefabricated modules. In contrast, the other concentrates on prefabrication at the window area as being the area with the highest density of details. Moreover, prefabricated modules for roofs and balconies are developed in the same way, i.e. customization to the project site depends on the interfaces between the modules, see figure 5.

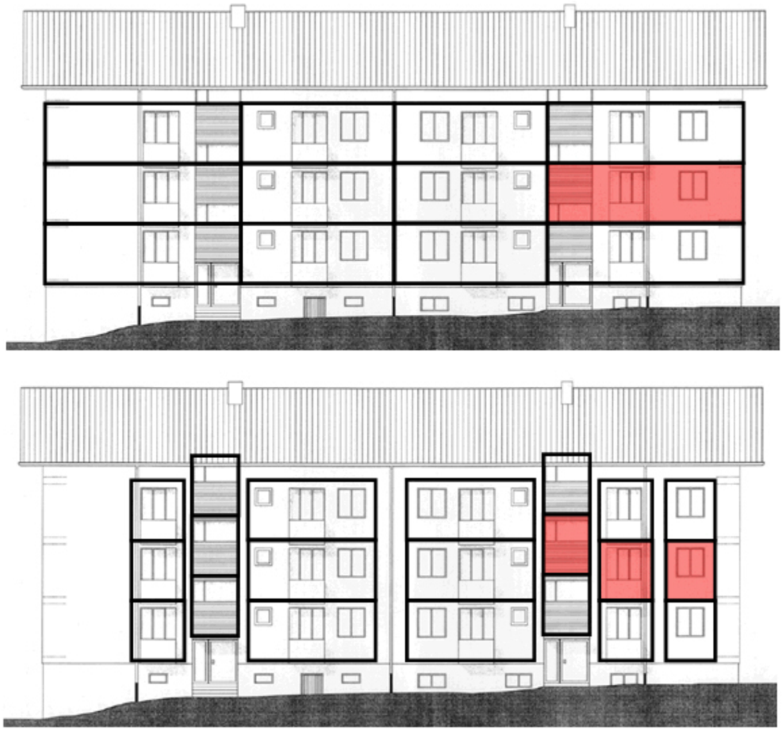


Figure 5: Two design and construction approaches for modular retrofit systems, i.e. the totally modular prefabricated design and the semi prefabricated design (adopted from Annex 50)

Fundamentally, and in line design guidelines developed in Annex 50 and confirmed by the MORE-CONNECT project, the module consists of the following layers:

1. An equalizing layer mounted on the existing outer wall;
2. A load bearing construction with insulation layer and integrated ducts;
3. A second layer of insulation material. The thickness of the insulation can be chosen depending on the desired U-value, and;
4. A cladding layer that can be prefabricated and delivered with the module, or mounted on site.

For example (case study De Kroeven, NL):
Wall construction U-value: 0.107 W/(m²·K)

- Existing brickwork 100 mm
- OSB 15 mm
- Cellulose fibre insulation 350 mm
- Damp open MDF 15 mm
- cavity 30 mm
- Natural slates 10 mm

>Total 520 mm

Façade and roof modules can be designed ‘freely’ for the following architecturally relevant points (Annex 50; Plug & Play 2D):

- Shape of the module (consider mounting possibilities)
- Recessions and projections (e.g. bays, dormers)
- Measurements of the modules (maximal measurements: 3.5 x 3.5 x 12 m)
- Measurement and number of openings
- Design of reveals and railings
- Construction material (wood, wood-metal, metal)
- Cladding material (all standard façade materials are possible)
- Shadowing elements (all standard sun protection systems can be integrated)
- Integration of solar energy (photovoltaic and photo thermal)
- Technical equipment (integrated risers for central ventilation and electrics, decentralized
- Ventilation systems, automatic shadowing systems, integration of solar energy)

Specification of module sizes
The specification of maximal possible and minimum sufficient sizes of the basic module is determined by criteria of transport and sizes of available material:

- What are available standardized sizes of necessary boards, sheets or plate material?
- How is it possible to minimize clippings?
- What is the maximum size of a module for transportation?
- What is the maximum size for delivering on-site and lifting to the façade due to the ranges for set-up area and possible lifting auxiliaries?

Specification of façade typology and module orientation
The orientation – vertically or horizontally – depends on the façade typology, the load bearing capacity and structural design building/facade. Different façade typologies have different effects on the orientation and subsequent design of the prefabricated modules. Framework facades for example affect a pattern – load bearing points are fixed and determine the module size. The façade typology and subsequently the orientation affect:

- Architectural appearance (dominated by horizontally or vertically lines)
- Assembling procedure
- Integration of components (glazing, ducts, BIPV et cetera)

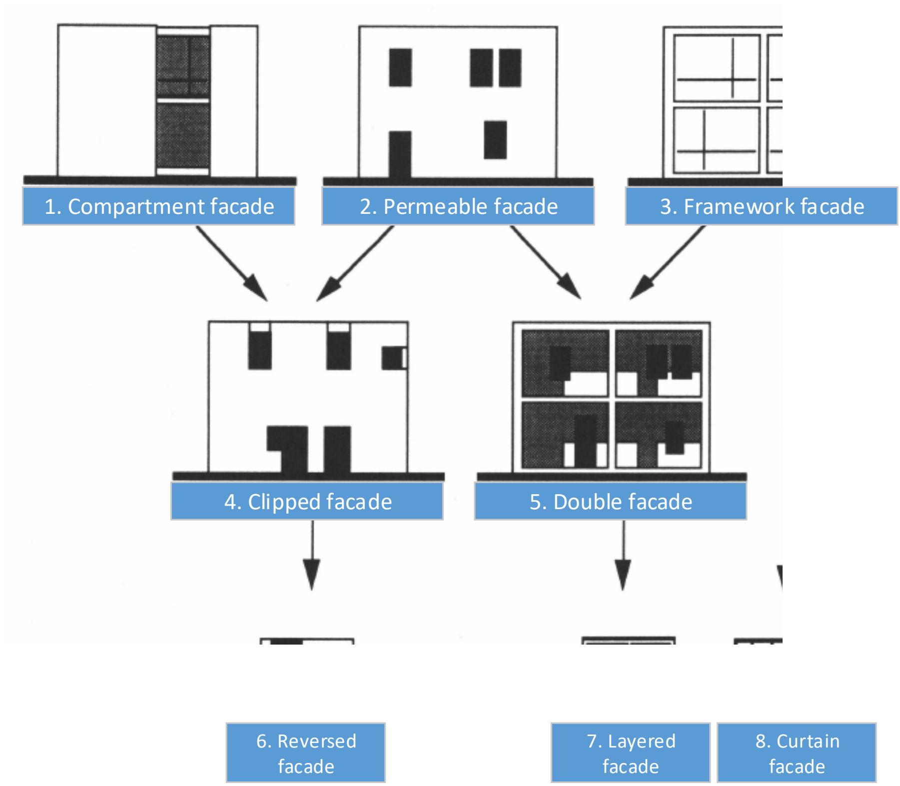


Figure 6: Main facade typologies affecting the orientation of the facade modules (adopted from TUDelft, 1994)

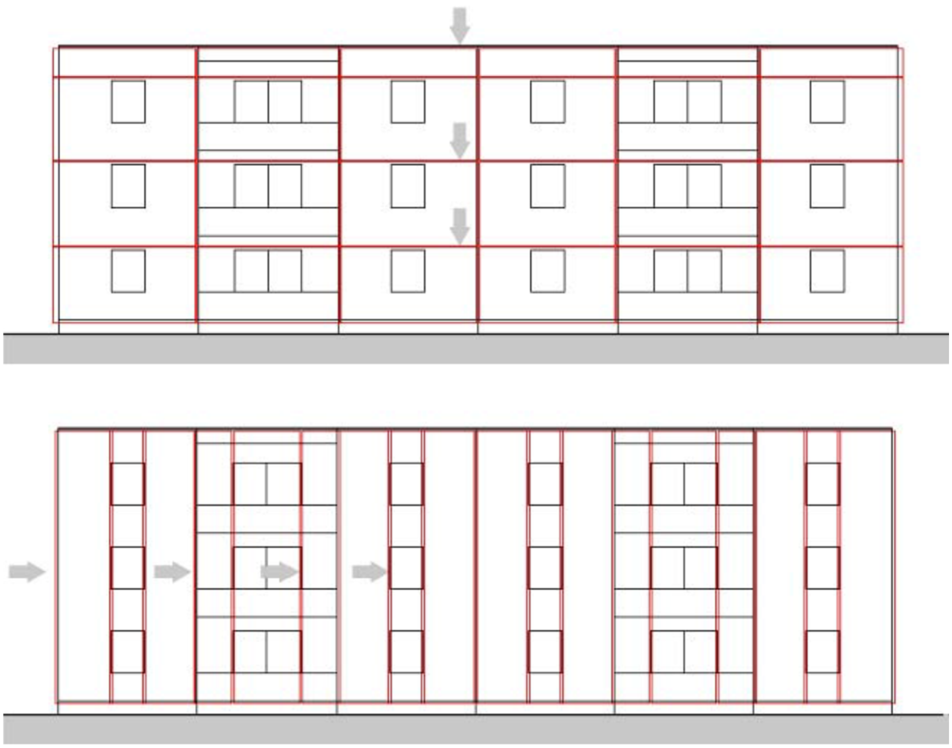


Figure 7: Grid applied to design the modular façade panels: horizontal or vertical orientation (adopted from Annex 50)

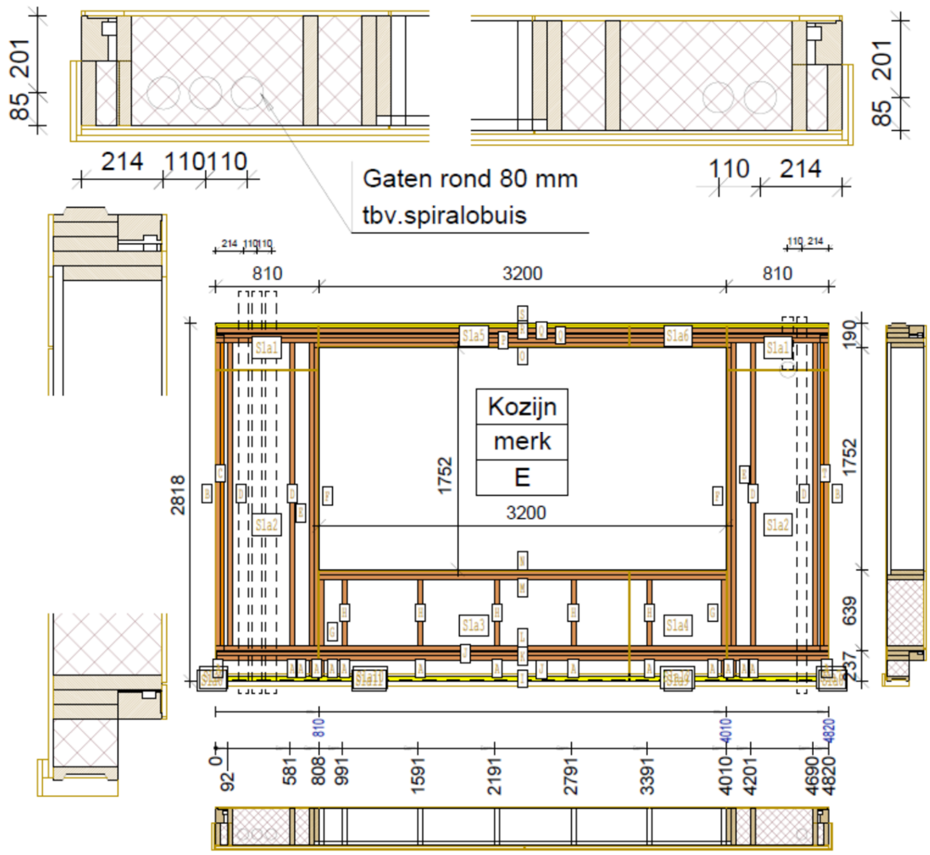


Figure 8: Basic module design developed by WEBO, producer of modular timber frame elements in the Netherlands

CHAPTER 4: (ARCHITECTURAL) DESIGN ASPECTS – A MORPHOLOGICAL OVERVIEW

4.1 Applying a morphological design approach

There are several innovative design methods. An example of this is the methodical design process based on a morphological design approach developed by Van den Kroonenberg (Siers, 2004; www.bouwnext.nl). The aim of a morphological overview is to systematically assess all possible solutions to a complex problem.
The methodical design process structures the design process into three parts:

1) Problem definition - In the first phase, the problem or improvement is defined. The result of this phase is a program of requirements.
2) Method determination - In order to achieve the stated goal, a certain function or (sub-)functions must be performed. A function can often be performed in several ways, i.e. alternatives. The alternatives can be expressed in schematic sketches and structured in a table or morphological overview. Vertically the functions are displayed in the morphological overview. In the horizontal direction the different alternatives for the functions are displayed. A number of alternatives can be combined into a logical design. This is called a structure. In the morphological overview, the structure is indicated by a structural line between the different alternatives. A final solution need to be selected from the prototypes developed. Typically, an objective selection technique is used, the so-called Multi criteria analysis (Kesselring method). The multi criteria analysis is performed based on the program of requirements developed in phase 1.
3) Formatting - In the third phase, the most suitable prototype is turned into a design, in this project the design of a facade module.

The morphological design strategy provides an approach to organize the design process of modules applied in the housing sector. Modularity offers flexibility and considerable freedom of design (Baldwin and Clark, 2000). The components which constitute the module can be organized within morphological overview. This components can be mixed and matched according predeveloped design rules. Flexibility not only relates to the architectural components. Technical components such (blinds, ducts et cetera), can be incorporated easily and cheaply into the prefabricated module at the factory. In addition, elements for active solar energy use can be integrated in all modules (Annex 50).

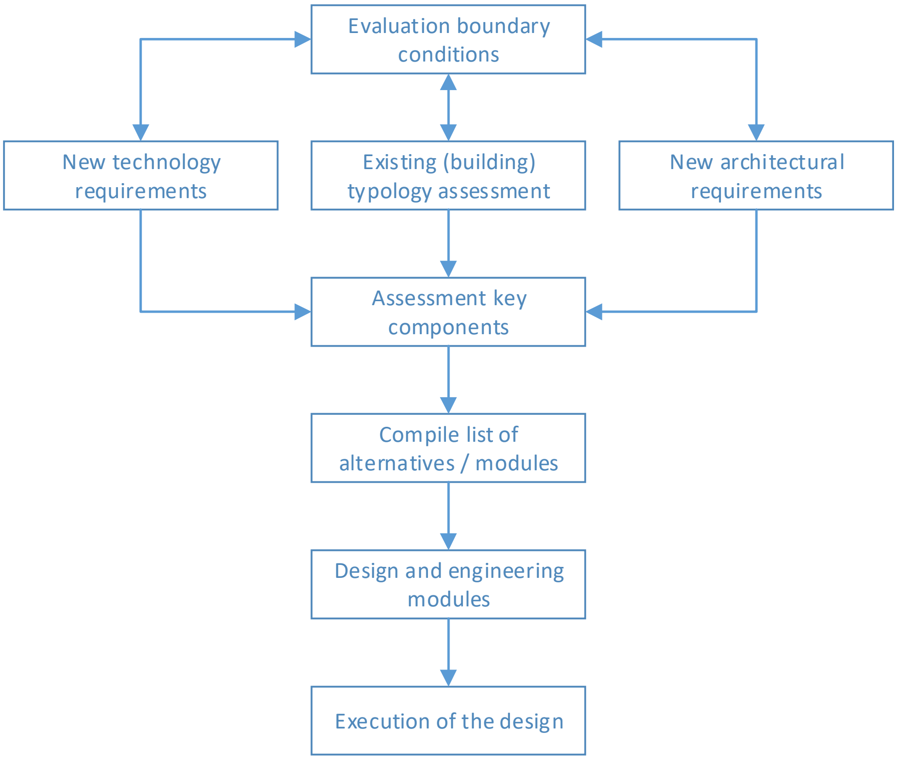


Figure 9: Design process

Derived from the morphological design strategy the design process of prefabricated façade modules include the following five phases (MORE-CONNECT WP2):

1. Assessing the boundary conditions of the building
2. Definition of technological and architectural requirements (including specific individual occupant needs) in relation to building extension and variability in comfort;
3. Compilation of a list of basic modules addressing design targets building upon the morphological overview;
4. Design and engineering of the module(s);
5. Execution of the project;

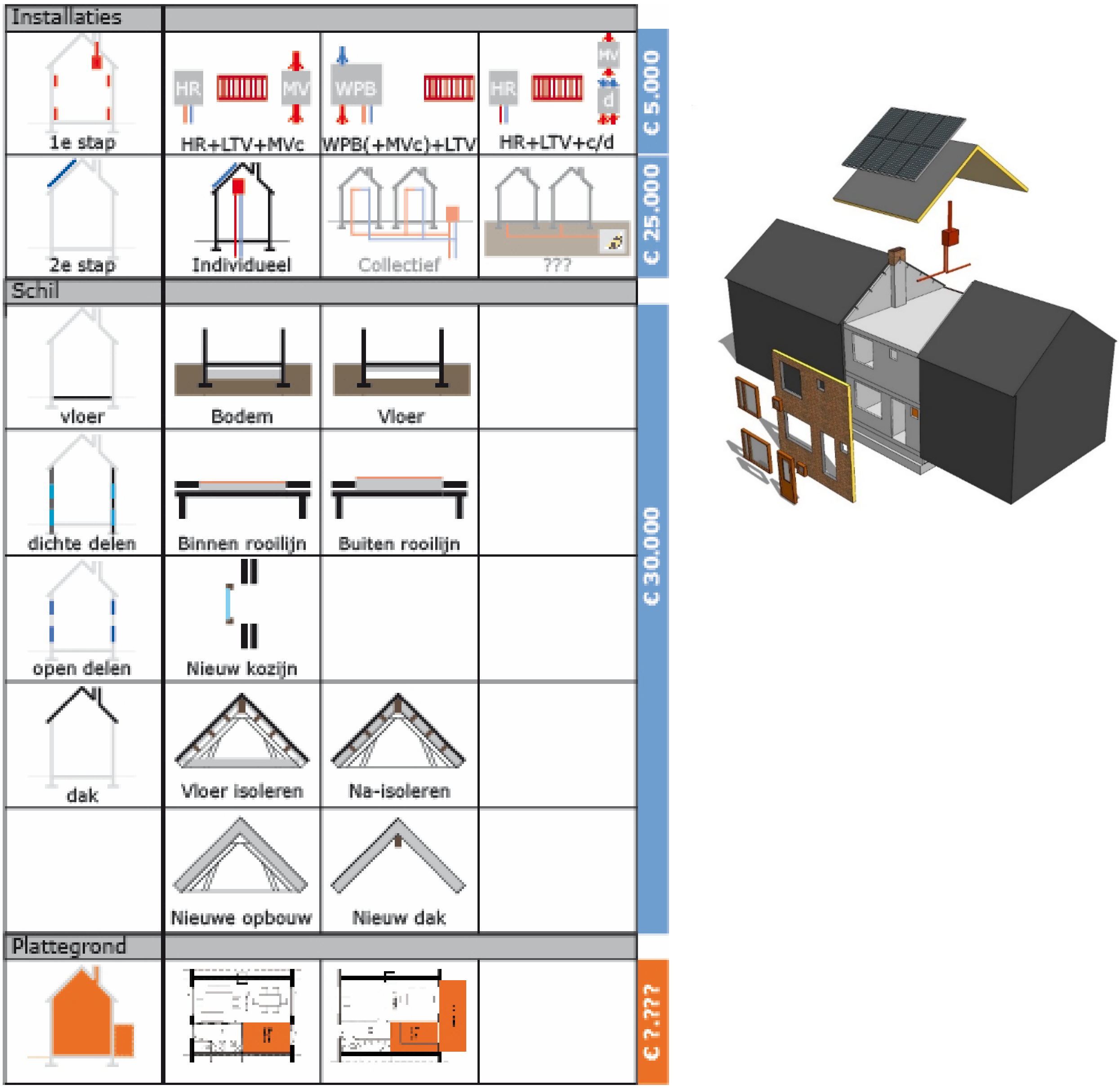


Figure 10: Design strategies could include a morphological design approach (adopted from Jonkers and Dijkmans, 2012 and http://www.hollands-ontwerp.nl/nominatie-hollands-ontwerp-award-2012-van-e-naar-beter/)

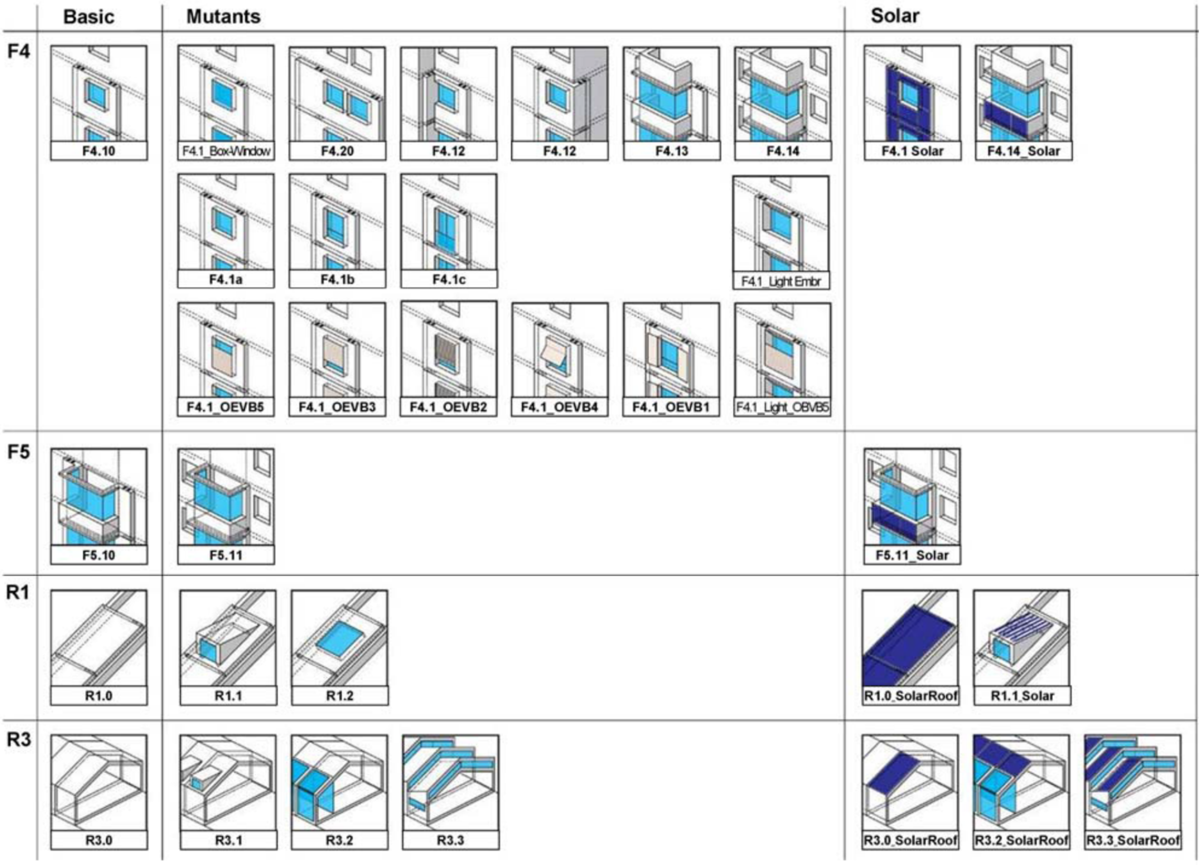


Figure 11: Design alternatives for specific modules which are part of the building envelope (Annex 50)

4.2 Background of the morphological design of a façade module

In this section some key design 'functions' are explained. These design functions are the cornerstones of the morphological overview with respect to designing façade modules. This section in particular builds upon the Annex 50 project.

Structural design

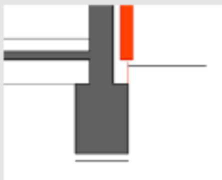
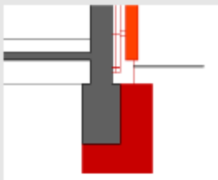
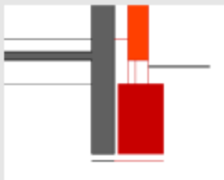
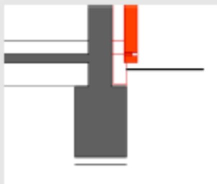
There are two different scenarios:

- The existing structure is able to bear the loads of the new façade system
- The existing structure is not able to bear the load of the new façade system

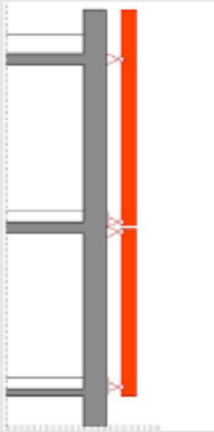
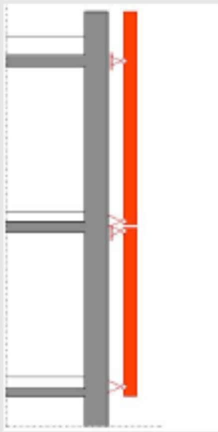
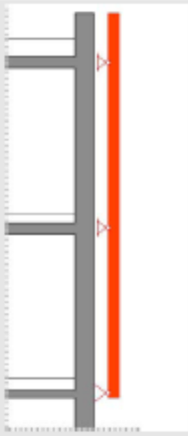
If the load bearing capacity is too little either a load distributing substructure is possible or the new façade has to be implemented as self-standing construction. Very often the foundation – invisible from outside – is forgotten. To avoid future settings an examination of the bearing capacity of the existing foundation shows which further loads can be carried. If capacities are too little either a reinforcement of the existing foundation helps or a new foundation is necessary.

Depending on whether a standing or suspended construction system is chosen, it is either possible to fix the modules directly upon the old façade or to mount a substructure. Depending on the module-size it is possible to implement a single-span beam construction or a continuous beam construction.

Furthermore the fastening subsurface influences the bearing system - it is either a massive structure, a skeleton or plate type construction.

	Suspended construction		Standing construction	
Substructure	Load application „suspension" within eaves, attic or roof	Load distributing substructure upon existing subsurface	Area-covering structure element (module acts as plate), additional fixing on the top necessary	Area-covering structure element (module acts as plate), several fixing points all over the façade
				
Foundation	Load transmission via existing construction → existing foundation is sufficient	Load transmission via existing construction → existing foundation has to be reinforced	New foundation	Load application upon the plinth via existing foundation
				
Dimensioning	Slimmer module sizes	Slimmer module sizes	Thicker module sizes necessary (Buckling stability)	Lower thickness of modules (shorter buckling length)

Massive constructions as subsurface offer the possibility of either direct fixing or mounting a substructure. A substructure evens out uneven façades in preliminary stages. A faster proceeding of further module assembling is possible. Nevertheless mounting the substructure needs preparation onsite and therefore either scaffolding or mobile cranes are necessary.
Fixing at floor level has the advantage of potential better load bearing properties, because mostly intermediate floors are made as reinforced concrete slabs or there is an existing grid beam. Even if walls have low load bearing capacities (like porous concrete or gas concrete,..) skeleton- or plate-type construction systems offer limited possibilities of direct fixing – the raster has to be adapted to the possible subsurface fixing points. The direct fixing extends the assembling procedure but no preliminary work is necessary.
Module sizes spanning more than one level are difficult to implement (transport and lifting). A possible size could be a sanding module spanning the entire height of the façade, but with limited width (about 3 meters).
Every system that uses more fixing points with smaller distances in-between reduces bearing loads and improves capacity to resist wind loads. Additionally the buckling length is reduced – the entire construction can be designed slimmer.

	Single-span beam construction Module system is mounted directly on subsurface or upon substructure	**Continuous beam construction** Continuous beam acts as substructure
Suspended construction	 Fixed support on top	 Fixed support on top
Standing construction	 Fixed support at the bottom	 Fixed support at the bottom
Evaluation	Modules have to be self-supporting. Additional substructure not mandatory. Without substructure every module has to be adjusted during assembling. Interchangeability of each module is possible.	Modules may be designed slimmer. Equalization of uneven subsurfaces by substructure. Assembling modules on substructures enables faster proceeding. Single modules are exchangeable.
Tolerances	Tolerances to allow movements emerging from temperature of each module.	Tolerances to allow movements emerging from temperature of each module.

Fixed support

Slide bearing

Fixed support at the bottom, slide bearing on top

Fixed support on the top, slide bearing at the bottom

The challenge within old buildings is the uncertainness of load bearing properties and load capacities as well as uneven subsurfaces or damages in the existing structure.
There is a broad product range of manufacturers offering fixing and mounting systems. They can be differed in dot-shaped and line supported fixings systems. Every dot-shaped fixing carries loads selectively and concentrated into subsurface – a disadvantage is when there are weak points within the old walls. Line supported fixing system are more flexible due to inhomogeneous existing structures.
Individual support brackets are suitable support areas for standing construction systems at the bottom.

But they can also be used for support of suspended or standing constructions at the top. Furthermore every fixing system has to be able to absorb movements and stresses caused by temperature-related expansions. The acceptance of these movements can be guaranteed by the arrangement of elongated holes between substructure and module.
Wooden substructures: Referring to the application of timer framework or wood-based boards it subsequently makes sense to use the same material for the substructures. The advantage is an easy workability – the customization on-site is easy, it is light weight compared to steel and different profiles are congenial available. The disadvantage – compared to steel or aluminium substructures is the lower load bearing capacity, a less form-retentive property and the combustibility. Due to fire prevention requirements it has to be proved in each case if a planned timber substructure is sufficient. eIn order to find adequate anchors or dowels or further fixing possibilities for different applications a lot of product catalogues or guidelines are available. Exemplary the following are mentioned (but there are more of them offering good advice):
www.fischer.de/desktopdefault.aspx/tabid-244/150_read-120/
www.hilti.at/data/editorials/-11888/ratgeber_duebel_online-2005.pdf. Download 09.11.2009
www.wuerth.de/de/medien/zul/duebel/uebersicht-duebel.pdf
www.werkzeugforum.de/fileadmin/pdfs/know_how_duebel.pdf

After a period of 20-25 years existing building services (HVAC27 systems) can be stated as outdated. The renewal of DHW - or heating-dissipation leads to measures within existing installation shafts or new ones have to be installed. But in any case it is necessary to carry out measures within the apartments.
Due to binding legal regulations about the protection of tenants or condominiums it is often very difficult to implement comprehensive renewal of piping if only one occupant does not agree on planned measures. But the chance to complete renovation of building structure and buildings services should not be forgotten. A comprehensive renovation (thermal envelope and building services) provides the possibility to optimize all systems and to complete renovation all at once.
The upgrading of piping or installation as a single measure at a later date is more expensive than carrying them out together with other works. And it will lead to further disturbance and discomfort for users.

Interface design between modules

The design of the module-chain influences first assembly, fixing and joining techniques, but has further implications for maintenance and repair. Interactions are shown in Table 26
The design of the joint formation is decisive for further work planning. On one hand the surface of the façade has to be waterproof against driving rain and the entire new envelope should constitute an air tight layer. But on the other hand – if there are damages or the necessity of access to the intermediate space the intermountability should be possible. Additionally tolerances between the single modules should allow an easy assembly and expansion and movements caused by temperature.

Cladding materials

As proven in several deep retrofitting projects with modular façade panels a diversity of (conventional) façade materials can be applied. From a structural perspective the overall weight of the module need to be considered, in particular while the finishing has a considerable impact of the overall weight. As a result the total weight of the façade could become a problem for the existing structure and the foundations and the strength of the structural interfaces has to be dimensioned accordingly. Next, architectural preferences and cultural heritage have to be contrasted with technical and economic consequences of the finishing selected. Overall, cladding alternatives can be subdivided according the following principles:

- Material selection
- Colour selection
- Pattern selection
- Installed during prefabrication versus on-site finishing

See figure 12 for a short impression of façade designs applied in the Netherlands.

Figure 12: Different cladding materials and designs applied in Dutch deep-retrofitting projects

<u>Integrated components</u>

Prefabricated modules bear the potential of easy integration of additional components. The basic assembly is done in the production facility under guaranteed conditions. Key to the integration of a variety of components are the interfaces between the components within the elements. This reflect the design rules of the module. These interfaces need to be engineered and completed carefully. Moreover, any expansion or extension (balconies, new arcades, winter gardens,..) can be prefabricated in a system-integrated way as components of the module or as module by itself. Key components, apart from the loadbearing structure, insulation and cladding include windows and glazing, shading and ducts and piping of the HVAC system.

Windows and glazing

Windows are substantial components within any façade – visually and technically demanding, due to their complexity. The interface between the basic module and the window frame need to be developed carefully with respect to airtightness and thermal bridges. The key performance indicators of windows and glazing include::

- Optimized supply with natural daylight
- Outlook for occupants
- Insight from outside

- Optimisation of solar gaining (hazard of overheating during summer)

Visual appearance is partly shaped by the position of the window within the module (exterior flush-mounted, centred in the reveal or interior flush-mounted)

Installation concept

Following measures can be necessary:

- Renewal or adoption of energy generation for DHW and space heating
- Renewal or adoption of the distribution and/or dissipation system for DHW and space heating
- Renewal or adoption of heat storage for DHW and space heating
- Renewal or adoption of further piping or wiring (water, sewage, electric wiring, television, …)

First of all it should come to the decision which installation has to be renewed. Existing installation should be checked:

- On functionality - it is not always necessary to demount fully functional installation.
- On their potential for optimisation –after renovation the entire system should be optimized from generation to distribution and dissipation

Shaping a new thermal envelope provides the possibility to integrate prefabricated installation modules on the outside of the existing wall but inside the new thermal envelope. Prefabricated installation inside the buildings is currently state-of-the-art. Not only shafts, even entire installation blocks or comprehensive sanitary blocks are prefabricated, transported on-site and fixed on the planned positions – only some connecting work is necessary. This technology can be adopted for external use.

But so far it has not been implemented during renovation – maybe the problem of arranging water conducted pipes on the cold outside has not been solved yet. But the advantage of installation on the outside within renovation is that installation works inside the apartments are reduced, occupants are less disturbed and it is possible to renew piping during occupancy. If one tenant refuses works within his flat it is possible to connect all other apartments with the new installation system because it is not necessary to lead pipes through this specific unit.

Active energy generation within building envelope: Building Integrated Photovoltaics (BIPV)

Until now the main objective of a façade was the protection against weather or outdoor conditions and the maintenance of indoor climate conditions as well as the visual appearance of a building. Active energy generation offers exciting opportunities from both a design and technological perspective. New opportunities emerge from the developments within the field of Building Integrated Photovoltaics (BIPV). BIPV as stated by subtask C of Task 15 (http://www.iea-pvps.org/) and based on EN 50583 and on the European Construction Product Regulation (CPR) 305/2011 is defined as (Technical Secretariat of European Commission, 2015 and Payet et al., 2014): Photovoltaic modules are considered to be building-integrated if the PV modules form construction product which is produced and placed on the market for incorporation in permanent manner in construction works or parts thereof, and the performance of which as an effect on the performance of the construction works with respect to the basic requirements for construction works. The different systems (photovoltaic, photo thermal, flat collectors, tube collectors, etc.) can be installed in/on the façade modules at the factory. So far, BIPV has not yet been applied at a large scale within façade modules. In contrast, several projects have been completed with BIPV applied on roofs.
Due to the complexity, architects and energy-engineers must co-operate in a very early planning stage.
A lot of relevant preliminary decisions of the architect during the design phase have significant influence on the further operation of the active systems. Orientation, incline, position and size are given by the shape of the thermal envelope.

4.3 Experiences from the MORE-CONNECT demonstrator projects

In addition to the theoretical background presented in the previous chapter, the morphological overview designed in the MORE-CONNECT project is inspired by the demonstrator project. The design- and engineering process is well documented in the MORE-CONNECT project. Detailed information about specific design- and engineering issues can be found in within a subsequent set of publications enlisted in table 2.

Table 2: Specific design- and engineering issues documented in the MORE-CONNECT project

Design- and engineering issues:	**MORE-CONNECT Deliverable (D)**
A set of Initial performance criteria and requirements	D2.1
A set of basic modular facade and roof elements (including renewable energy production and integration of HP insulation)	D2.2
Modular prefab integrated HVAC units (MORE-CONNECT 'engines')	D2.3
A set of smart Plug & Play connectors, (mechanical, air tightness, hydraulic, air, electric and ICT)	D2.4
Advanced controls for the modular elements (facade, roof, engine)	D2.5
Tool to optimize the combined energy and materials performance of the alternative configurations in relation to local typologies	D3.2
State-of-the-art deep renovation concept with modular prefabricated façade and roof panels: Experiences from the Netherlands	D3.3
Instruction guide of materials alternatives in relation to reuse and the combined energy and materials prefab element impacts and reuse of demolition materials	D3.5
Sets of embedded integrated control systems – optimizing control strategies according to user requirements and energy demands and long term monitoring system and data analysis	D3.7
Guide with concepts of renovation packages for different types of housing	D3.8
Method for digital inventory of buildings based on advanced geomatics	D4.1
BIM application: technologies used for the design process	D4.3

Below the key design- and engineering issues of five demonstrator projects of Estonia, Latvia, Portugal, Czech Republic and the Netherlands are briefly discussed.

Estonia - There were two main issues which needed to be solved:

- Deviations were found, both vertically and horizontally, and the design of the façade incorporates sufficient adjusting space during on-site mounting of the façade modules
- The connectors to the existing building needed to be engineered

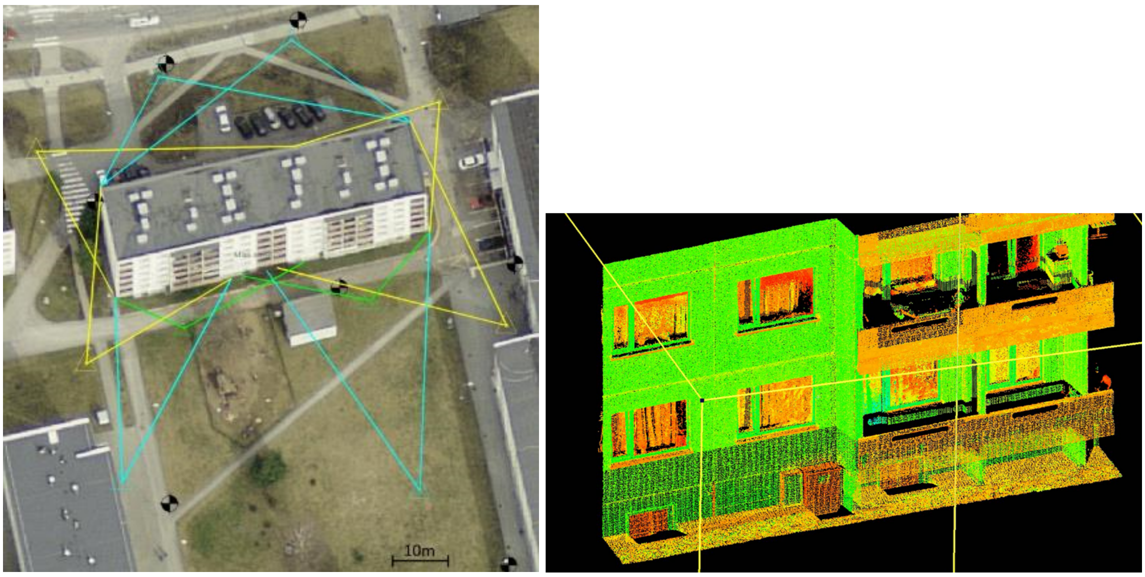


Figure 13: Deviations were found both vertically and horizontally

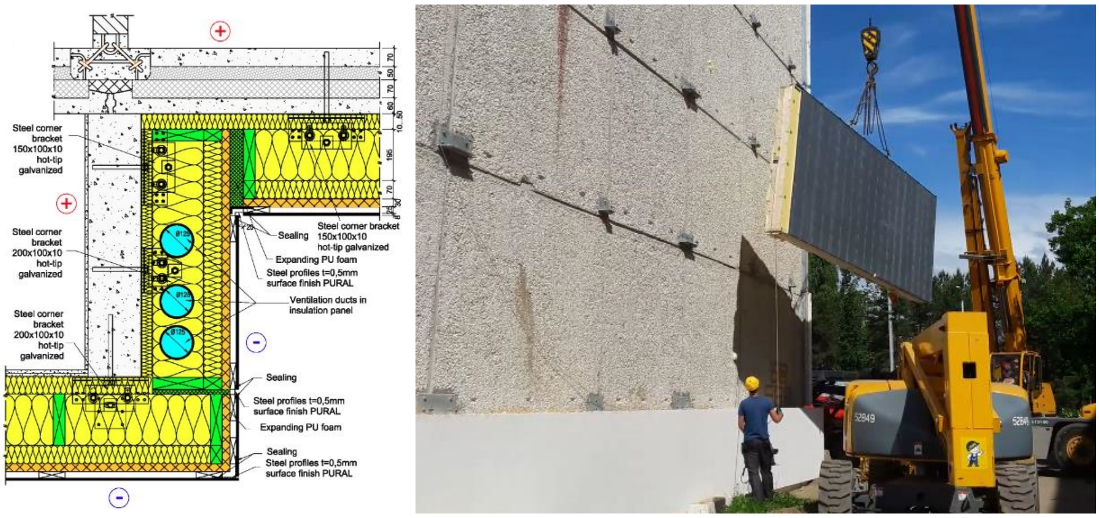


Figure 14: Example of designed connections between modules and the existing wall

Latvia – The key design parameters are wall vertical deviations which should be taken into account at the early design stage. Also the existing window vertical and horizontal deviations play a crucial role in facade layout design. The replacement of existing PVC windows has the highest payback time as well as higher environmental impact. The panel solution should include extra flexible connection layer to connect panel and existing wall. This layer should insure necessary level of air tightness and thermal resistance. Currently there are not common understanding between constructors and architects on such layer solution. Further long term research on existing solution suitability should be done. As another important factor is lack of lifting equipment. Currently widely used cranes and tackelages do not allow precise panel movement and positing locking close to the renovated wall.

Portugal – From the design and engineering perspective, there is still room for improvement in relation to the panel assembly, which has implications in the design of the connections to the building.
One of the key parameters in the demonstrator in Portugal is related with the additional layer of mineral wool to be applied between the existing wall and the prefabricated module. This additional layer has the dual objective of serving as an interface between these two rigid surfaces and, simultaneously, preventing thermal bridges. This issue is related with the physical connection between the modular solution and the existing wall, as well as the connection between panels (Figure 3). These points are both of significance regarding a successful implementation and assembly of the modular solution at the construction site.

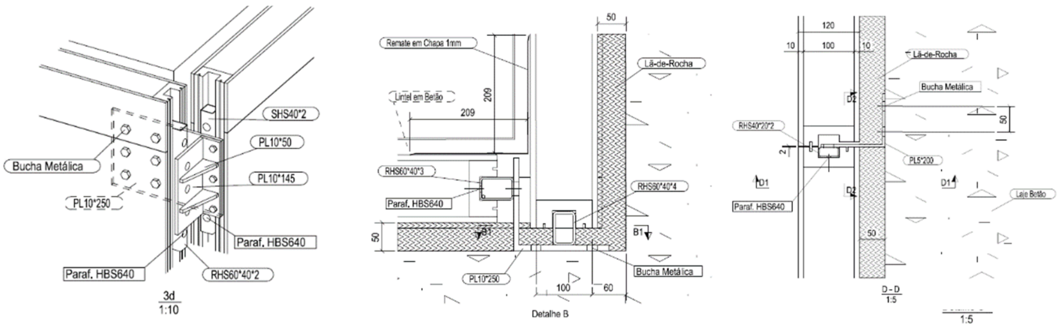


Figure 15: Example of designed connections between modules and between modules and the existing wall

In addition, there is still factors involved in the production process (and therefore related with the engineering of the product) that can be optimized, as for instance the injection of the polyurethane foam, which, at the moment, is outsourced and that in the future should be integrated in a single facility production process.

Czech Republic – The following main technical issues that had to be solved:

- Universal steel anchors capable to bear additional balcony at any position without possibility to be supported by non-bearing masonry
- Minimalized thickness of the additive modules because of very thick original wall (45 cm)
- Smart hydraulic and ventilation connections between modules providing the real-time information about its condition
- Steel anchors for thermal insulation & ventilation ducts creating one complete item out of them for easier and faster montage
- Additive insulated ventilation chimney fixed on façade
- Plaster connections in the façade
- Air-tight covering of the window siding in the same time providing possibility of observation of all electrical systems integrated in the module and HVAC systems
- Foundation covering boards made of high-performance concrete (HPC)

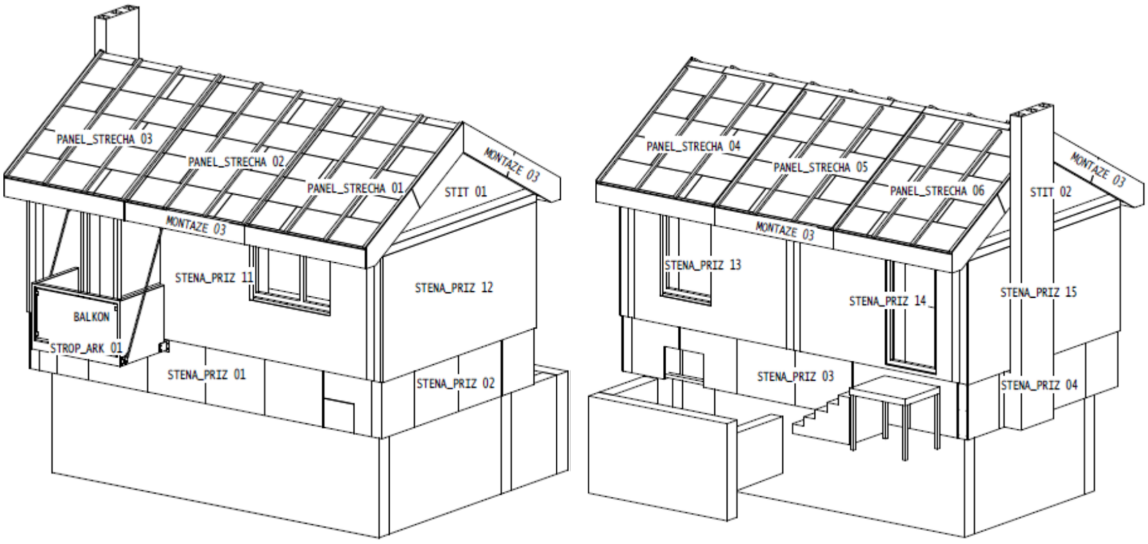


Figure 16: Installation layout of modules

Figure 17: Fixed row of modules, window siding before covering, façade plaster connection, pre-installed ventilation ducts

Figure 18: Connection of modules, fixation of balcony, HPC foundation covering boards (bottom row)

The Netherlands – The following main issues with respect to the design and engineering of the project had a quite large impact (quality):

- Initial (architectural) design adjusted according predetermined design rules related to the modular façade system: building extension like balconies were removed to ensure airtightness interfaces between the façade modules.
- Modular façade consists of several fixed design rules in terms of standards modules and interfaces. Nevertheless some unique, project specific, detailed solutions need to be developed (design flexibility). Fixed design rule contribute to an efficient design and engineering process; (aesthetic) design 'bottlenecks' are identified and solved early in the project.
- WEBO is responsible for the quality of the (integrated) design of the façade. Within tradition construction projects several stakeholders share the responsibility of design like precast penal floor systems.
- The façade modules have been improved after its application in the demonstration project: the EPS on which the brick slips are glued is replaced by battens and cement fiber board. This has some advantages with respect to:
  - Guarantee on wind and waterproofing in the long term in case of mechanical damage
  - Improvement fire protection
  - Production efficiency (simplification)

Figure 19: Building extensions are removed and subsequently new balconies are installed in front of the building façade.

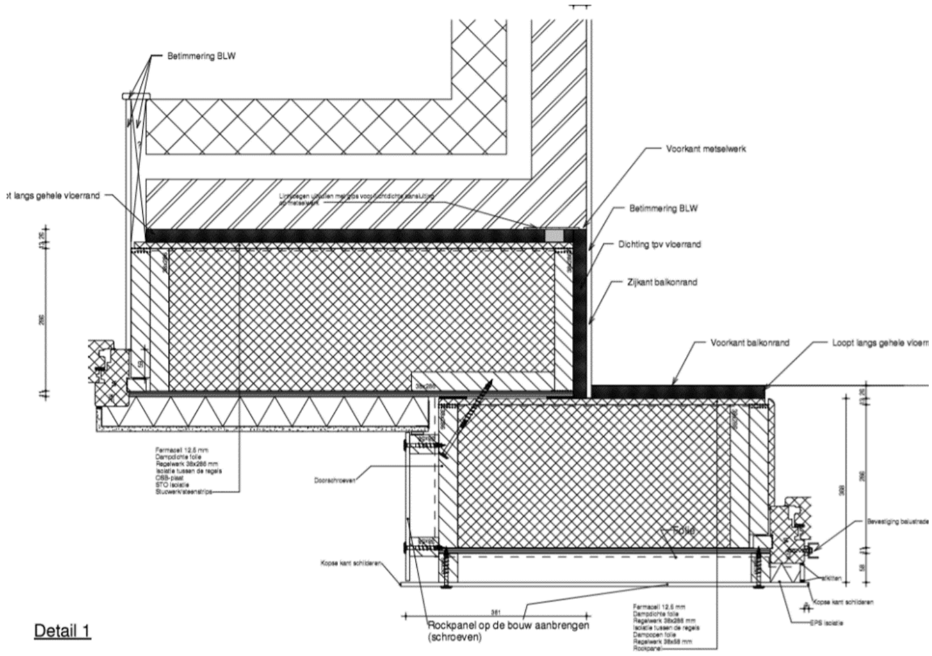


Figure 20: Project specific interface, horizontal (overlapping) connection between façade modules

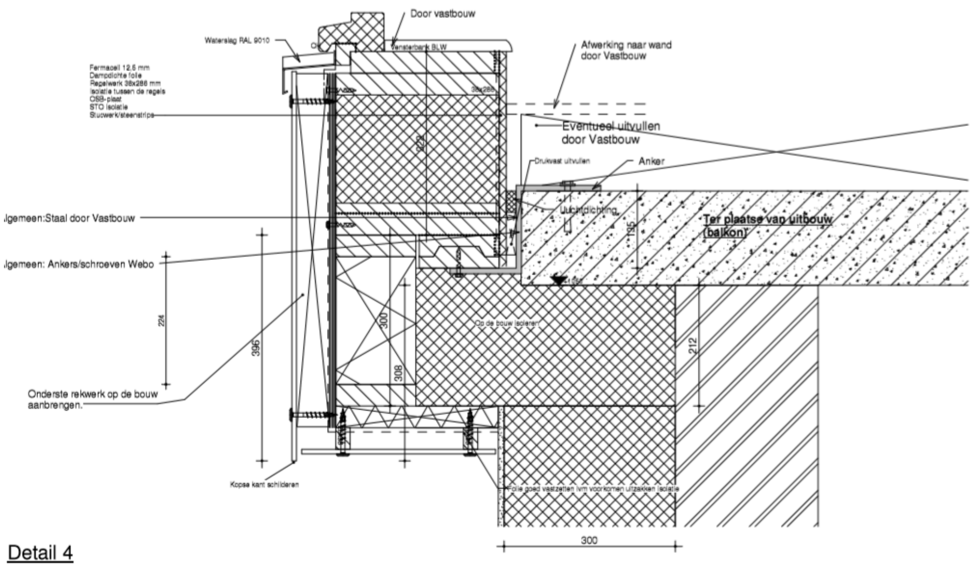


Figure 21: Project specific interface, vertical connection between façade module and foundation covering

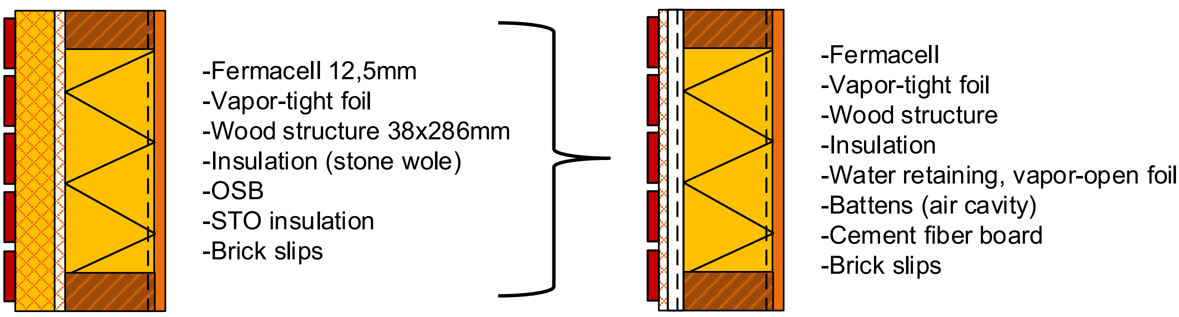


Figure 22: The façade modules have been improved after its application in the demonstration project: the EPS on which the brick slips are glued is replaced by battens and cement fiber board

Moreover, the deep-renovation demonstration projects, in particular with respect to the "lessons learned" are well documented, see table 3.

Table 3: Specific design- and engineering issues documented in the MORE-CONNECT project

Design- and engineering issues:	**MORE-CONNECT Deliverable (D)**
Specifications of design process	D5.2
Prototypes of prefabricated modular renovation elements	D5.3
Lessons learned (pre-)production and on-site mounting	D5.4
Evaluation quality of construction works	D5.6
Analysis of the total deep-renovation project	D5.9

The demonstrator projects are used to compose the morphological overview presented in the next section.

4.4 Design guide and tool

In order to design the MORE-CONNECT deep-renovation solution, several functions or (sub-)functions must be performed. For every function several alternative solutions can be developed. The alternatives composing the MORE-CONNECT deep-renovation are expressed in schematic sketches and structured in a morphological overview (see below). Vertically the functions are displayed and in the horizontal direction the different alternatives for the functions are displayed. A number of alternatives can be combined into a structure or logical design. In the morphological overview, the structure is indicated by a structural line between the different alternatives.

However, to apply the morphological overview in the design process specialized knowledge is required. While it could not be expected that in particular homeowners end/or tenants possess the knowledge and skills about deep-renovation. In the same respect, homeowners and/or tenants are mostly likely not aware of the deep-renovation solutions available in the market. Therefore, the morphological overview have been used to develop the MORE-CONNECT DESIGN TOOL. Based on some elementary parameters, the design tool composes the deep-renovation package and indicate the merits with respect to energy performance, the financial investment required and also indicate some specific design aspects with respect to aesthetic appearance, renovation time and the level of nuisance during project execution. The basic structure of the MORE-CONNECT DESIGN TOOL is presented below. A more detailed description of the MORE-CONNECT DESIGN TOOL can be found in a separate report, Deliverable 4.2 (this report specifically link the design guidelines with end-user requirements and design preferences).

MORE-CONNECT DESIGN TOOL

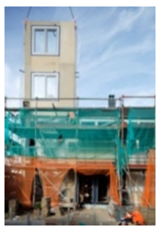
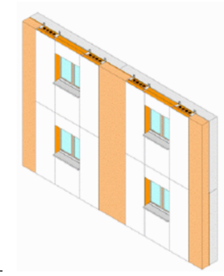
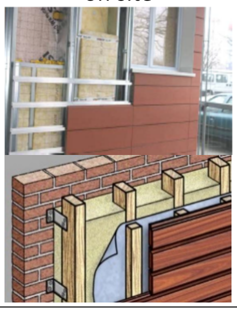
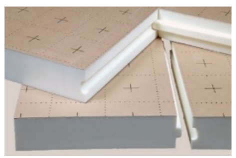
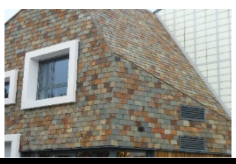
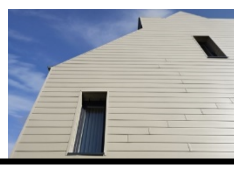
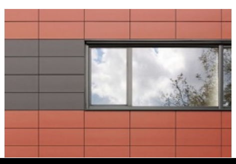
HOUSING SITUATION		
	Current housing situation	
	Residents	3
	Resident Composition	two income household with child
	Type of house	Duplex house
	Construction year	2000 - 2010
	Country	Netherlands
	Providence	Limburg
	Technical Aspects	
	Desired indoor climate [ºC]	20
	Living area [m²]	100
	Ceiling height [m]	2,5
	Available roof surface [m²]	40
	Roof direction	South-West
	Roof gradient	20 degrees - low slope
	Shading	No shadow
	Window surface [m²]	20
	Air permeability	1 (basic)
	Current type of wall construction	Solid brick wall

Current type of window	Single glazing
Current type of roof insulation	No insulation
Current type of heating source	Electric boiler
Heat distribution	Electric IR Radiation Panels
Current type ventilation	system A - natural air supply and exhaust
Energy consumption	
Electrical [kWh/yr.]	3000
Gas [m³/yr.]	1400
Domestic hot water [m³/yr.]	Generously

RENOVATION	Custom Package Creator		COST
	Basic Module and interface	Prefabricated, horizontal orientation modules	
	New type of Insulation (material)	Aerogel insulation	
	Interface foundation	Existing foundation need to be reinforced	
	Interface building	Standing construction: mounted on foundation, add. Fixing on top	
	Openings	Wooden frame with air chambers	
	Glazing	Double glazing	
	Integrated components	Shading / blinds	
	New type of wall insulation	No improvement	
	New type of roof insulation	No insulation	
	Cladding	Panels	
	PV Panels	yes to cover electrical consumption	8400,00
	amount of PV panels	**12**	
	Heat pump	no	7000,00
	New type of ventilation	NO IMPROVEMENT	
	Efficiency ventilation system [%]	95	
	Estimated Cost of investments [€]	**15400,00**	**TOTAL**

RESULTS	Energy Results	
	Gas savings [m³/yr.]	335
	New gas consumption [m³/yr.]	1065
	Generated electro [kWh/yr.]	3210
	Electrical consumption [kWh/yr.]	3000
	Total electrical net [kWh/yr.]	-210
	Energy-neutral	0%
	Financial Results	
	Total investment [€]	15400,00
	Earnings [€/yr.]	937,26
	Earnings [€/month]	78,11
	Return of investment [yr.]	16,4
	Other results	
	Renovation time [short-long]	0,53
	Renovation nuisance [little-heavy]	0,60

Design guide: morphological overview MORE-CONNECT façade modules

	A	B	C	E	F	G
Concept						
Basic module and interface (module-building) *Prefabricated panels: Structural Insulated Panels (SIPs – standard, I-beam, bamboo)*	Prefabricated, horizontal orientation modules 	Prefabricated, vertical orientation modules 	Semi prefabricated, combination of prefab modules and on-site finishing 	Traditional – small components assembled on site 		
Layers	-Insulation (between panel and exiting façade) -Timber structure with insulation (SiPS) - Covering (ventilated)	-Insulation (between panel and exiting façade) -Timber structure with insulation (SiPS) - Covering PS and plaster				
Insulation (material)	Mineral / glass wool 	Cellulose (recycled paper) 	PUR/XPS/PE insulation 	Wood-fiber insulation 	Bio-based (cotton; flax; hemp) 	Aerogel insulation 
(N)ZEB installation concept	Decentralized heating system: gas boiler + low temp + MV(c) (+ PV)	Decentralized heating system: heat pump (air) + gas boiler + low temp (+ PV)	Decentralized heating system: heat pump (water) + low temperature + MV(c-d) (+ PV)	Central heating system: district heating; industrial residual heating		
Interfaces and components						
Interface foundation	Load transmission through existing structure (existing found. is sufficient)	Existing foundation need to be reinforced / replaced	'Structural adaptor' between module and foundation			
Interface building	Suspended construction: horizontal (floor and roof) structures	Suspended construction: sub-structure upon existing surface (façade)	Standing construction: mounted on foundation, add. fixing on top	Standing construction: fixed upon existing surface (façade)		
Interface module	Fixed interface	Flexible (re-mountable)				
Ducts and piping HVAC	Ventilation ducts integrated in the module (mech. vent.)	Ventilation ducts included in separated spaces (mech. vent.)	Ventilation box (including heat recovery)	Natural (demand-driven) ventilation via façade openings	Summer night ventilation	
Openings	No frame	Thermally decoupled wooden frame (accoya)	Aluminium frame with wooden finishing (thermally decoupled)	Timber frame with air chambers	Plastic frame with air chambers	
Glazing	Double glazing	Triple glazing				
Other integrated components	Shading / blinds	Energy modules (engine)				
Active energy generation: BIPV	Smart windows	BIPV mounted on/ integrated into module				
Cladding	Masonry (brick slips) 	Plaster 	Tiles 	Cladding 	Panels 	

CHAPTER 5: CONCLUSION

5.1 Summary

This report includes a first version of design guidelines for modular façade elements. Design guidelines are key to the adoption and diffusion of modular innovations like MORE-CONNECT, i.e. design guidelines constitute the relative advantage of MORE-CONNECT over alternative deep retrofitting solutions (Rogers, 2003; Van Oorschot, Hofman, & Halman, 2016). The design guidelines presented in this report are organized according an innovative structured design strategy, and build upon the concept of modularity, experiences from several innovation projects in the field of deep-retrofitting and insights from the MORE-CONNECT project. This reports contributes in three ways. First, the report addresses the theoretical background of modularity and its potential in the residential sector. In addition, housing is decomposed to its key modules. While the MORE-CONNECT project primarily goals link to modularize the design and construction of the building envelope during deep-retrofitting, this report in particular focus on the façade module. Although other components are equally important. Second, the report organizes the design requirements involved with the design and assembly of prefabricated façade modules. Finally, the main contribution encompass a morphological overview of design alternatives which constitute the prefabricated, modular façade elements. Based on specific project requirements designers could select the most suitable components. The morphological overview could also be a framework to harmonize design and production of the modules from a mass-customization perspective. It provides the boundary conditions for designers from an industrial production perspective but also provides the opportunity to mix and match design alternative to customize the façade module. As a result, and already available in the market, from the morphological overview (BIM) configurators can be developed to include occupants in the design cq. decision-making process. As a result, the morphological overview was used to construct the MORE-CONNECT DESING TOOL. Based on some elementary parameters, the design tool composes the deep-renovation package and indicate the merits with respect to energy performance, the financial investment required and also indicate some specific design aspects with respect to aesthetic appearance, renovation time and the level of nuisance during project execution.

5.2 Limitations and suggestions for further improvement

The design guidelines presented in this report are still under development while the experiences from the MORE-CONNECT demonstration projects are not fully accounted for. The design guidelines presented could also benefit from experts in the field of deep-retrofitting, in particular architects and engineers of modular facades (elements).

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*(*including several related articles published by Yuri van Bergen; Haico van Nunen and Martin Liebregts on the same website)*