The relevance of adaptable façade systems: an evaluation through scenario planning

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Abstract

Due to the static nature of conventional buildings, demolition is often unavoidable when requirements have changed. At that moment, all invested resources are wasted. In contrast, introducing adaptability in the design phase of buildings and their elements, e.g. façades, facilitates future transformations, extends buildings' service life, and has thus the potential to reduce the building industry's environmental impact. Previous research has illustrated how existing adaptable façade systems allow the material efficient addition, elimination, substitution and relocation of components to adjust their performance to new demands [1]. Without compromising the other elements' reuse, adaptable façades can meet functional, technical and social changes while being of enduring value. To guarantee a reasonable and feasible implementation, it should be investigated which alteration every façade should enable. Given a building's specific context, such as the building's envisioned service life or ongoing urban developments, the façade does not need to be completely adaptable, but should enable relevant transformations. This paper discusses when and why it would be necessary to transform façades. Proposing a scenario planning method, it illustrates the insight that can be created through divergent service life models. Several criteria ensure that representative scenarios and models are developed, for example the consideration of already ongoing changes and relevant uncertainties. In this paper, scenarios are applicable to dwellings and proceed from changes in household composition and size. The study of three family dwellings in Flanders finally illustrates how a selection of service life models allows evaluating and selecting the most feasible façade system and design. This study acts as a proof-of-concept for informing designers about the added value of future-proof façade systems.

Key words: Transformable façades, Adaptive façades, Scenario planning, Household scenarios, Service life models, Design for Change

1. Introduction

The built environment is in constant change. The value of buildings depends on their utility under these changes. Besides a building's diminishing technical condition [2], changes of external factors influence that value too. Think of regulations, technological improvements and environmental awareness [3]. They put the building sector under pressure since the contemporary building stock's nature is static. The buildings cannot adapt easily to changing requirements; their value declines and demolition often becomes unavoidable. At that moment, buildings or building parts are destroyed before they have reached the end of their technical service life and all invested resources are wasted. To avoid buildings being prematurely obsolete, they should be able to adapt to their changing environment [4]. Adaptable buildings facilitate transformations, improve the ease of refurbishments and repairs and do so with minimal waste production, as demolishing and replacing of components is avoided [5]. This way, buildings are expected to keep their value longer, give them the potential to change efficiently with their environment and to reduce their environmental life cycle impact [3, 6].

Façades have a significant effect on the environmental impact of a building [1, 6]. They occupy a large part of the building envelope and are closely related to the overall building performance. However, the façades are generally the most rigid and the most expensive building component [2]. This means that the façades are often the last building component that will be adapted. At the same time, the performances of the façade are linked to several dynamic factors, such as: functional change of space, privacy control, changes in the flux of people or the occupants' wellbeing and needs [8]. The question is thus to which extent it is adequate to make façades adaptable. To answer that question, it should be known when and where transformations will occur in order to anticipate and enable them only where they are relevant [9].

2. Methodology

To evaluate the potential added value of transformable façades, a scenario planning method is proposed. When designing adaptable buildings, designers should make provisions for future changes [10]. As the future is not predictable, scenario planning is used as a research method. Scenario planning has the potential to develop alternative imaginable futures [11]. Hence, it raises awareness by evaluating and comparing the resilience of the design alternatives [9].

This paper focuses on residential buildings in Flanders. Household scenarios are developed which proceed from changes in both household composition and size. Several criteria ensure that representative scenarios are developed, for example the consideration of already ongoing changes and relevant uncertainties [12]. These household scenarios will be applied on three family dwellings through research by design. These designs result in divergent functional service life models of the façades. These service life models allow then to select the most feasible, environmental friendly, resilient or robust façade system. The study acts as a proof-of-concept for informing designers about the added value of future-proof façade systems.

3. Developing scenarios

In this paper, it is questioned whether adaptable façades are useful for responding to changes in functional needs and if so, to which extent. The developed scenarios are decisive for the generated insights. From accurate scenarios, accurate service life models can be developed. These can then provide accurate information to the design team and the client [13]. Before developing scenarios, predetermined elements and critical uncertainties should be known [9]. Predetermined elements are slow-changing phenomena. Critical uncertainties are uncertain elements which have an influence on the success of the alternative potential futures. An example of a predetermined element in building design is changes in demography. From previous observations projections can be generated about the households' future formation [14].

The factors that affect the final level of adaptability the most are the driving forces. These driving forces move the plot of a scenario. The driving forces which affect the level of adaptability of façades in dwellings are related to households. Based on regional studies, the driving forces in this case, the Flemish households, are [9]:

1. The increasingly divergent household compositions, and thus also the more divergent household needs (**Traditional/divergent household compositions**). They result in two prospects [13]:
   - Functional changes: The spaces in the dwelling are used for other purposes and this results in changes in the façade.
     - Traditional household compositions: The traditional household in Flanders is still a couple with children [15], where the children grow up and leave the original household.
     - Divergent household compositions*:* Other family composition began to emerge in the late twentieth century, together with changes in moral values [16]. Today, the definition of family is still expanding. Families can include generational differences, cultural differences, organisational family structures, etc.
   - Aesthetic/privacy changes: The façade is adapted to meet the altered needs of the household (same function) to reach a certain degree of user satisfaction.
2. The speed of change of these needs, and thus the speed of change of household composition or the speed of relocation of households (**High/low changing rate)**
   - Trends in housing show that the recurrence of changing sequences is occurring more frequently during time [17]. van Nunen noticed that, by observing six renovation projects, changing cycles of 15, 30 and 60 years in buildings are common [13]. However, the façade is a rigid building component. Therefore, the 15 year-cycle is used for the 'high changing rate'. The average age of an obsolete residential building is 32 years [18]. Accordingly, a cycle of 30 years is taken for the low changing rate.
   - The service life models will include changes made over 60 years as it is common in life cycle assessments to use an operational lifetime of approximately 50 years [19].

Technological drivers and economic drivers are not in the framework of this paper. Of course, they influence the level of adaptability of façades (e.g. new and innovative technologies or the financial status of the building owner has an influence on building choices) but it is assumed that alterations are realised at any cost and with any technical or structural solution. This assumption suits the goal of this paper: exploring when façade alterations are relevant to the user.

From these two driving forces four scenarios can be set up. The two main driving forces are each placed on an axis and this results in a scenario matrix (Figure 1).

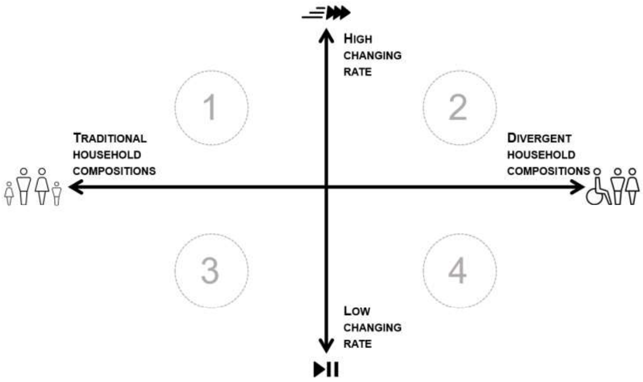


Figure 1: Scenario matrix of household typologies in Flanders resulting from placing the two main driving forces on axes, establishing four scenarios.

Scenarios evolve in time. They are thus presented on a time axis in Figure 2. Each scenario starts with traditional family in year 0 (today), for which the case studies are built.

1. **High changing rate – Traditional household compositions**
   The households' changing rate is high and the household composition remains traditional. Hence, when a family moves out, the next family has similar requirements.
2. **High changing rate – Divergent household compositions**
   The households' changing rate is high and the household composition increasingly diverse.
   Façade alterations at a high changing rate are needed to create a façade layout that offer the required spaces with the suitable level of privacy.
3. **Low changing rate – Traditional household compositions**
   The households' changing rate is low and the household composition remains traditional. Requirements change together with the family's evolution over time. The traditional household will evolve step by step, with the transformation of the children from toddlers to young adults. Correspondingly, at a certain age, the parents will need more care, but want to age in place.
4. **Low changing rate – Divergent household compositions**
   The households' changing rate is low and the household composition increasingly diverse. The household's requirements can change radically. A radical change is taken every 30 years. These changes can influence the requirements for the façade.

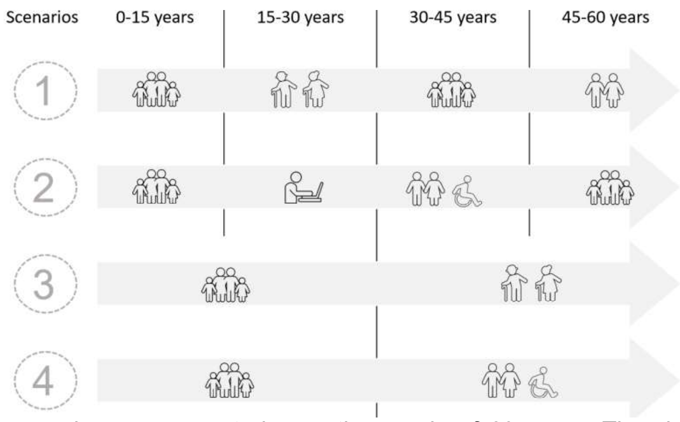


Figure 2: The four developed scenarios are presented on a time scale of 60 years. The chosen household typologies represent an assumption of the course of the scenarios. They can differ while still fitting in the storyline of the scenarios.

Not every change of a driver results in a façade alteration. Alterations are only needed when the current state and the desired state are of a certain difference. It is questioned which difference will trigger a façade alteration [9]. To answer that question, three family dwellings in Flanders are studied by which transformations they should enable to house the household compositions. The two extreme households are plotted to the three case studies. These two households are the traditional household and the kangaroo household. As a result, the less diverse households, for example a home-working household, are also included in the range between the more extreme households. In a kangaroo dwelling, elderly live together with their children or other relatives, but their unit is separated from the main dwelling unit. The dwelling should thus be divided in a main dwelling unit and a wheelchair accessible unit on the ground floor [20]. In this composition, where a dwelling is divided in two units, it can also be possible, for example, to use one unit for short term renting or for a homeworking space.

4. Terraced houses in Flanders: 3 case studies

The housing ideal of the Flemish families is since the fifties the single-family home with a garden [21]. This enclosed urban house typology occupies a large part of the built area in Flanders. According to the cadastral statistics, most residential buildings are open buildings (approx. 888,000), followed by closed buildings/ terraced houses (650,000) [22]. Moreover, the terraced house typology becomes more popular for its compactness and urban location and, but also for its rising estate prices and the announced halt of new allotments in Flanders [23].

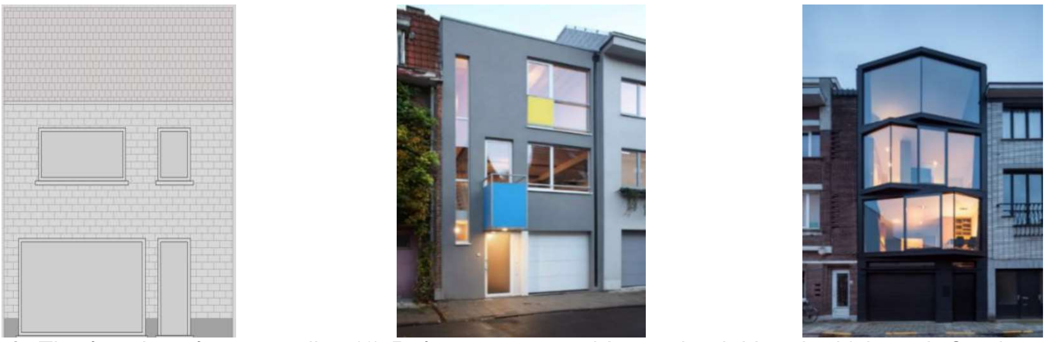


Figure 3: The façades of case studies (1) Reference terraced house by J. Van der Veken, J. Creylman, T. Lenaerts, (2) Schoonejans house by ICI Architectes and (3) Abeel House by MiASS Architectuur.

1. **Case study 1: Reference terraced house**: The reference terraced house is designed based on a statistical analysis by Van der Veken et al. in their study 'Study on cost-optimal levels of the minimum energy performance requirements of new residential buildings' in 2015. They analysed the housing stock in Flanders based on parameters such as construction type (open, semi-open, closed construction of an apartment building), the gross floor area, etc. The terrace house is one of the five reference houses for the building stock in Flanders. It is designed with conventional building materials such as brick and concrete and it has an inclined roof. It contains two bedrooms and one bathroom [24].
2. **Case study 2: Schoonejans house by ICI Architectes**: The second case study is a terraced house where the aim was to generate a rational and efficient house. The architects opted for a ground floor that can function as a part of the whole house or that can function as a separate unit, a studio apartment. The ground floor is connected to the backyard. Moreover, the owner required to build in a fast and cheap way. Therefore, the structure consists of precast concrete elements. Large fixed and 'tilt and turn' windows were provided in the front façade. The building, built in 2014, refers to the modernistic architecture of the 50's. Modernistic architecture did not have a large base in Belgium at that time. Therefore, it is valuable to research this case study and its façade as it is built in the opposite style than the typical Flemish pragmatic style. It has two bedrooms and one bathroom.
3. **Case study 3: Abeel House by MiASS Architectuur**: The third terraced house, designed by Mias Sys of *Steven Vandenborre Architecten* in 2013, consists of a stack of three glass volumes, put on top of a solid base. Every floor has shifting angles. The focus of the house is the façade's geometry, materialisation and the connection with the interior. The relevance of this case study lays in the influence of the façade on the users' behaviour, as the large glass parties maximize transparency and diminishes privacy. It can also be considered as the counterpart of the other case studies, as the large glass windows are not common or rational.

5. Applying scenarios to case studies

With the developed scenarios and the selected case studies, the scenarios can now be applied to each case. This section discusses how the application of scenarios 2 and 4 on Case study 1 (indicated in Table 1) can lead to service life models. The service life models will indicate when and where the façades should adapt to meet the required functional performances. From those service life models, suitable and feasible façade systems can be selected. This façade system should enable transformations only where they are relevant.

	Case study 1	Case study 2	Case study 3
Scenario 1	High changing rate – Traditional household compositions	High changing rate – Traditional household compositions	High changing rate – Traditional household compositions
Scenario 2	**High changing rate – Divergent household compositions**	High changing rate – Divergent household compositions	High changing rate – Divergent household compositions
Scenario 3	Low changing rate – Traditional household compositions	Low changing rate – Traditional household compositions	Low changing rate – Traditional household compositions
Scenario 4	**Low changing rate – Divergent household compositions**	Low changing rate – Divergent household compositions	Low changing rate – Divergent household compositions

Table 1: The case studies are plotted against the scenarios, which results in service life models. In this paper, the process of applying scenario 2 and 4 (highlighted) to Case study 1 is explained.

To test the resilience of an adaptable façade, the two extreme households are applied to Case study 1 through a research by design method. The extreme households are the traditional family household and the kangaroo household (Annex 1). To let Case study 1 satisfy the needs of the kangaroo household, four façade alterations are required (Figures 4 and 5). All alterations occur at the back façade, where mainly doors and windows need to be removed or added. In this case, the main reason for the need of alterations is the change of circulation. By applying the needed alterations with demountable façade elements for housing a kangaroo household in a family dwelling is sufficient or even excessive to be able to house other less extreme household types, such as a home practice or a short renting option.

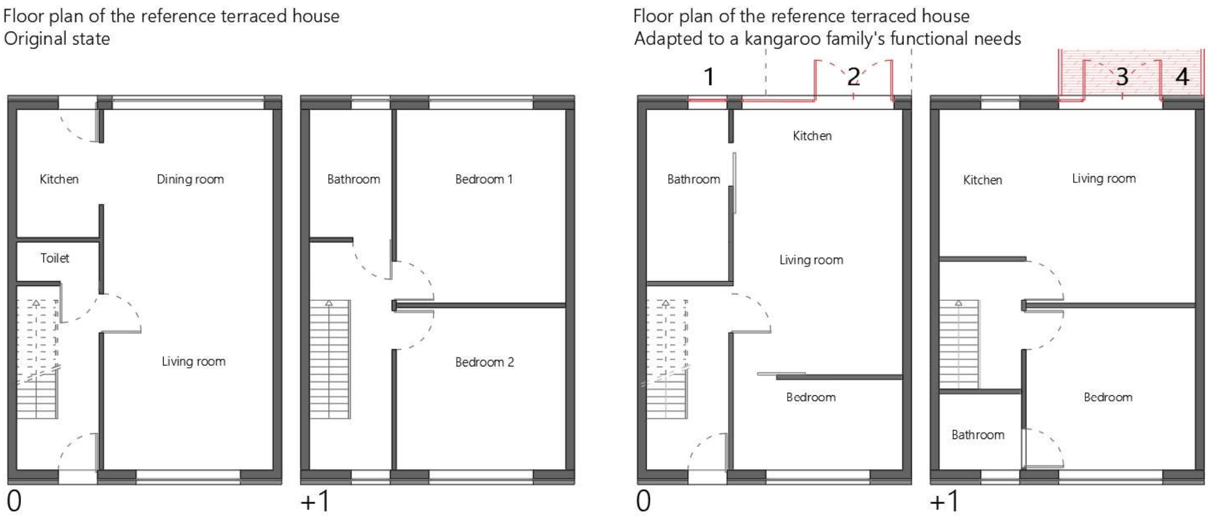
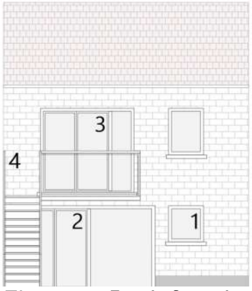


Figure 4: Floor plans of Case study 1 (the reference terraced house) to house a traditional household (left) and a kangaroo household (right). The left floor plans are the original floor plans, initially designed for a traditional household. The four changes needed in the façade to be able to house a kangaroo household are numbered and drawn in red.



1. The kitchen door is replaced by a bathroom window (ground floor, back façade)
2. A door is added to the dining room window (ground floor, back façade).
3. A door is added to the bedroom window (first floor, back façade).
4. A terrace is anchored to the façade to allow circulation from the first floor to the garden (first floor, back façade)

Figure 5: Back façade of Case study 1 adapted to the needs of a kangaroo household. The four needed alterations are indicated.

Other alterations could be done if other needs must be met, such as privacy needs. Also, applying these households' needs to the other case studies, results in other alterations. For example, also the front façade could need alterations or alterations are only needed on the ground floor's façades (Annex 1).

Findings on the cumulative changes per case study are:

- All case studies: In a narrow urban house, the façade at the back has the largest potential to be changed, as the garden provides a private space.
- Case study 2: It was provided from the design phase that a part of the house, the ground floor, can be separated from the rest of the house. Consequently, the house can adapt more easily to changing needs and this has a direct influence on the need to adapt the façade. The more adaptable other components and spaces are, the smaller the need to adapt the façade.
- Case studies 2 and 3: Both cases have garages on the ground floor which can serve as a useful extra space when the needs of the household(s) change. This results in the same conclusion: the more adaptable other components and spaces are, the smaller the need to adapt the façade.

6. Service life models for Case study 1

Knowing the needed alterations per case study and per household type, the service life models can be established by applying the different household scenarios. In this paper, a service life model is a representation of the functional performance of the façades during a period of time [25]. It is assumed that the functional performance exceeds the minimum acceptable needs of households every 15 or 30 years, in such a way that the façade(s) need to be transformed. The service life models thus represent the desired replacement cycles of the façades based on the impact of households' needs and households' changing rate. They are thus examined to reveal if implementing an adaptable part in the façade could extend this service life.

Hereunder four service life models are presented of Case study 1 (Figures 6 to 9). In this paper, one service life model is presented for each scenario.

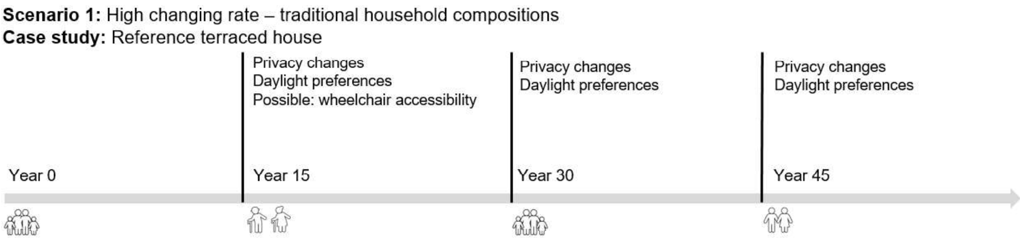


*Figure 6: **Service life model 1:** a possible outcome of applying scenario 1 to case study 1. Change resulting from functional needs will be minimal and alterations will be caused by aesthetic and privacy preferences, as a new traditional household moves at a high changing rate.*

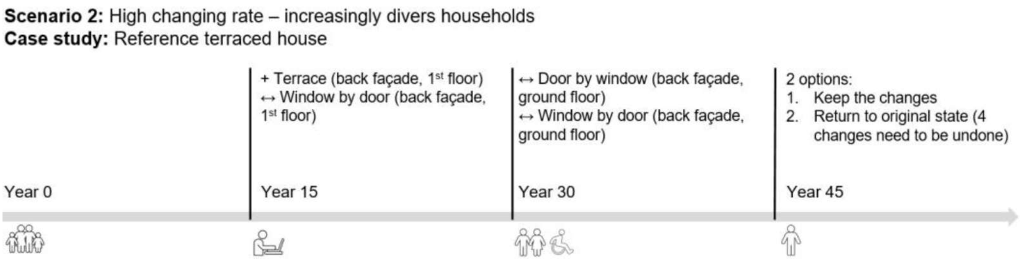


*Figure 7: **Service life model 2:** a possible outcome of scenario 2 to case study 1. The façade alterations will mainly consist out of joinery displacement, which will occur at a high changing rate.*

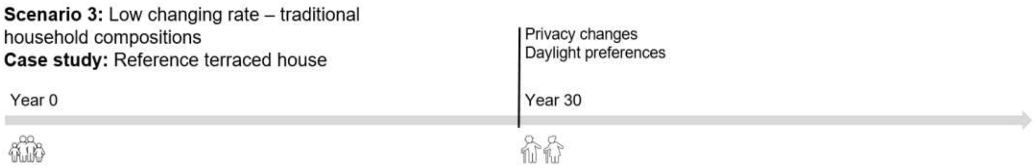


*Figure 8: **Service life model 3:** a possible outcome of scenario 3 to case study 1. The functional requirements change with the family. Hence, less changes are needed over time and the changes will be less radical.*

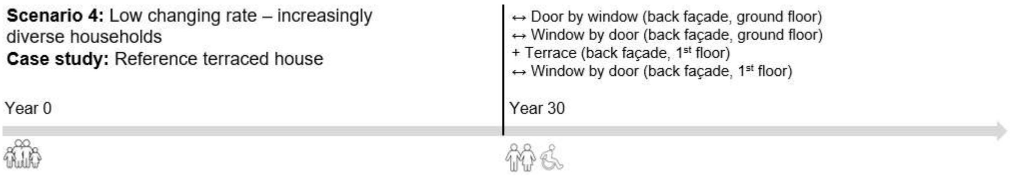


*Figure 9: **Service life model 4:** a possible outcome of scenario 4 to case study 1. Changes only occur every 30 years, however, as increasingly diverse households emerge, it will be radical changes.*

When the alterations happen, for example the four façade alterations in Case study 1 (Figure 4 and 5), depends on the scenario. Also, the service life models can include the same cumulative changes after 60 years. For example, the service life models of scenario 2 and 4 (Figure 7 and 9) can have applied the same alterations after 60 years. The difference is that it will happen at a different pace; in scenario 2 some alterations will already occur after 15 years, while in scenario 4 there is a more drastic change after 30 years.

Before selecting a suitable façade system for the considered household scenarios and service life models, some reflections on the service life models should be made:

- The developed and considered service life models influence the selection of the suitable façade system for a particular case. The removal or addition of a service life model has thus an influence on the subsequent choice of the façade.
- These service life models are developed for a specific set of household typologies. They can differ when other household typologies are considered, such as larger families, cultural differences, etc. This would have an influence on the research by design part, the required alterations and ultimately on the selection of a suitable façade system.

7. Selection façade system

The generated service life models can be used as a decision-making instrument. They indicate explicitly where and when change is needed. With this knowledge a façade solution can be suggested. Although, for each set of service life models, different façade solutions can be chosen.

7.1 Case study 1: reference terraced house

The reference terraced house is able to adapt to divergent household types and their spatial and functional needs by allowing four façade alterations. As those alterations all occur at the back façade, it is proposed to limit the implementation of the adaptable part to the back façade. The other façades can remain static. A static well-informed design is perhaps more sustainable than a fully adaptable building part which will never be transformed in the future. Moreover, façades are often the most rigid and most expensive building component and are probably the last building component that will be adapted when needs change. The distinction between adaptable and static building parts is important as different service life expectancies have an influence on material, component and connection choice. For example, in an adaptable element, a reversible connection will be chosen as in a static element, the most durable element will be chosen, which is perhaps not reversible. Consequently, the façades should thus not be completely adaptable to be future-proof. The adaptable façade parts are able to disassemble, to recover and reuse the elements and material when an adaptation is needed. The Flanders' public waste agency OVAM published design principles to apply adaptability to buildings and their components [26]. For building components, the applicable principles are reversibility, simplicity and speed of (dis)assembly, durability, independence and reusability.

The service life models of case study 1 show that mainly external windows and doors need to be replaced. The average life expectancy of external windows and doors (in timber, aluminium and PVC) is about 30 years [27]. Therefore, the joinery should be reusable (high changing rate) and recyclable (low changing rate). External doors and window systems are usually prefabricated elements and are connected to the external wall with dry connections. This could facilitate removal without waste creation and without damaging adjacent components. However, often finishes (paint finishing or sealing strips) prevent this ease of removal. Thus, demounting a door or a window itself can be inefficient and complex.

A possible solution is a system of replaceable panels, including doors, large windows or smaller windows (Figure 10). This way, the panel can be replaced instead of doors and windows separately. The panels are non-bearing.Their structure consists of light weight steel or wood framing and can be assembled with reversible connections, such as screws and bolts. Other layers, such as the insulation and the finishing layer, should also apply the adaptability design principles. An example of a demountable detailing of an external wall is given in Figure 10. The shape and the size of the panels plays an important role in reuse possibilities. Then the dwelling itself is not the starting point, but the panels are designed in such a way that they are also reusable in other construction projects. For example, the length of the back façade is 6,30 m. Thereupon, a system of panels with length 90 cm or a multiple could be used to create a system that is based on a standard grid.

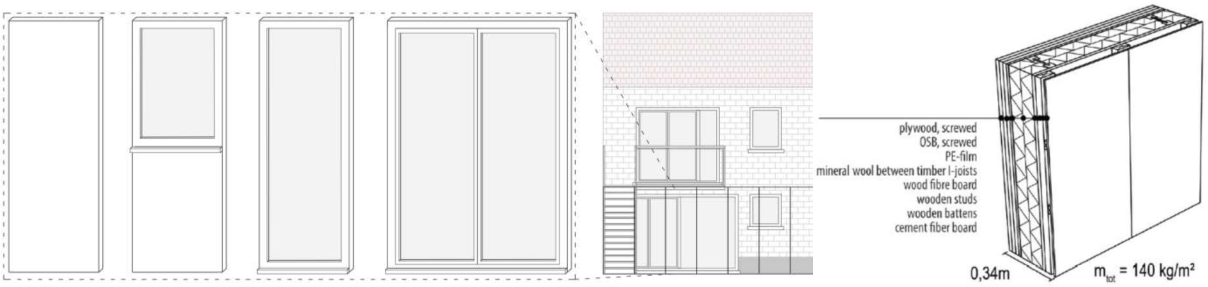


Figure 10: A system of replaceable panels could offer a reversible solution instead of doors and windows, which are often complex to demount (left). The layers of the panel can apply the adaptability principles through demountable detailing (right) [28].

Furthermore, the changing rate of households has also an influence on the choice of the façade solution. With a high changing rate, the elements should be more adaptable or have a higher reuse potential. If the changing rate is low, such as in Service life model 3, where there is possibly no façade alteration needed, it could be considered to place a static façade. However, there is no absolute certainty of the evolution in the future. If the designer decides to implement a static façade and the household composition changes, the chance that the building will become obsolete earlier might be larger due to inadequate circulation routes, spatial issues or high refurbishment costs.

The selection of a façade solution also depends on the fact if it is a new construction project or a renovation project. For the new building, the adaptable part will be applied on the building parts where the study indicates that there will probably be an alteration during the following years while for a renovation project, only when an alteration is needed for the first time the static part would be replaced with an adaptable part. Then, the next time an adaptation is required at the same place, it can be easily adapted and the same (static) mistake was not made twice.

7.2 Case study 2: Schoonejans House

The designer and the owner of the Schoonejans House decided in the design phase to design a multipurpose house. The house can function in two ways: it can function as a detached house with four bedrooms or as a two-floor apartment plus an independent studio. In this paper, with particular scenarios, only to adapt the house to a kangaroo dwelling, one transformation is needed (Annex 1). It demonstrates that if a unit of the house has the possibility to be separated (on the ground floor) possibly less transformations are needed in the future. The inner adaptable design has thus an influence on the façades' adaptation requirements.

7.3 Case study 3: Abeel House

The Abeel House is suited for divergent household types. The main reason is that the house has a garage which can serve as a useful extra space when the needs of the household(s) change. Besides, the house has large windows in the front façade, designed for the current owner of the house. If it should adapt to meet the altered needs of another (similar type) household, it could entail privacy issues.

8. Conclusions and discussion

The aim of this paper was to discuss when and why it would be effective to implement adaptable façade systems. Adaptable façade systems can adjust their performance to new demands. Hence, they avoid being prematurely out-of-date and unnecessary demolition.

The methodology is based on a scenario planning method. This method has the aim to make provisions for alternative imaginable future changes. By doing this, it advocates to enable multiple applications of a building, rather than restricting it to one function. In this study, the scenarios were applied to dwellings; three terraced houses were chosen as case studies. The household scenarios proceeded from (1) the increasingly divergent household compositions and (2) the changing rate of moving households. The application of the scenarios resulted in service life models. A selection of service life models allowed selecting a feasible façade system and design.

It can be stated that not all façades should be completely adaptable to obtain a future-proof building. For terraced houses, the main reason for the need of alterations is the change of circulation towards the backyard. That can be claimed from the fact that mainly doors and windows needed to be removed or added. For example, in case study 1, which has the most changes over 60 years, all alterations occur at the back façade. The adaptable part could thus be limited to the back façade. Making the distinction between adaptable and static building parts remains important. Different service life expectancies have an influence on the final choice of material, component and connection.

The developed service life models are case-specific. For example, apart from the envelope, the adaptability level of the interior spaces affects the façades' adaptation requirements too. If a house has a multifunctional space, or if the ground floor can operate independently, such as in case studies 2 and 3, less façade alterations are needed when the household's needs change.

There is no absolute certainty of the evolution in the future. As the service life models of case study 1 showed, more divergent households can move in, which enlarges the chance for the need to adapt the façade. Moreover, if there is a high changing rate of households moving in and out, the façade elements should be more adaptable or have a higher reuse potential. In contrast, if the changing rate is low and the households rather traditional, there is possibly no façade alteration needed. The designer or the client could consider placing a static façade or an adaptable one based on life cycle cost or life cycle environmental impact.

The critical challenge to stakeholders and designers, who have different interests and influence over the project, is the inability to prepare for unforeseeable futures [29]. This developed method can help to get insight in the possibilities of adaptable façades for a future-proof building. To increase the accuracy of the methodology at the use of adaptable façade systems, it is proposed to enlarge the scope to other building typologies and contexts. This study focused on functional drivers; the next step is to apply technological and economic drivers. They would facilitate the re-application of the method, reveal the added value of adaptable façade systems in multiple ways and the reinforce the argument of implementing adaptable façade systems.

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Annex A

	Traditional household (parents + 2 children)	Work from home	Short term renting	Kangaroo household	Cumulative changes per case study
Case study 1: Reference terraced house	-	**Add**: terrace at the back, first floor, **Replace** window by door at terrace	**Add**: terrace at the back, first floor, **Replace** window by door at terrace	**Replace**: Door by window at the back, ground floor **Replace**: Window by door at the back, ground floor **Add**: terrace at the back, first floor; **Replace** window by door at terrace	8
Case study 2: Schoonejans House by ICI Architects	-	-	-	**Replace**: garage door by window	1
Case study 3: Abeel House by MiASS Architectuur	-	**Add**: Window at the back, ground floor **Replace**: garage door by window	**Add**: Window at the back, ground floor **Replace**: garage door by window	**Add**: Window at the back, ground floor **Replace**: garage door by window	6
Cumulative changes per household type	0	4	4	7	

Table 2: The household types are plotted against case studies. It is studied, through a research by design method, which alterations are needed to adapt the case studies to the specific household types, starting from a dwelling designed for a traditional household. The amount of cumulative alterations is mentioned in the right column and the bottom row.

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