This doctoral research aims to narrow the current gap between practice and theory of ‘Design for Change’. To achieve this goal, the causes of the current limited application are identified in the first part of this chapter. Second, support was given during a part of the design process of several case studies as exploratory and participatory research.

Parts of this chapter have been published in [1], [2], [3], [4] and [5].
1. INTRODUCTION

Research conducted at our own research group 'Transform' makes clear that for a variety of functions and problems, technical solutions to anticipate changing needs can be found through those principles. Nevertheless, the use of transformable building elements is limited to a small scale and niche functions today, such as temporary or transitional buildings.

However, no research has been conducted so far to identify the causes of the limited application of transformational capacity in buildings in the specific case of Belgium. Therefore, a survey with important stakeholders of the Belgian construction sector was conducted in this chapter to identify the challenges, the opportunities and possible answers to those challenges.

Moreover, in the last decades, many researchers searched for new principles to facilitate reuse of building components, as mentioned in previous chapter. Prescriptive guidelines were established and assessment tools developed to support architects in the design of reusable and recyclable buildings. However, this research has not been implemented in practice on a large scale. The current gap between research and practice should be narrowed by participating in the design process of several case studies as exploratory and participatory research, which was done during this research. The participation in the design process of four case studies was very enriching as it could be noticed how architects actually needed support to apply principles of 'Design for Change'. In addition, the outcomes of the survey were checked in reality. Each design process happened differently due to a variety of functions and contexts. On the one hand the design teams were helped applying transformable key concepts and on the other hand their feedback helped me to improve theoretical design proposals and research results. For that reason, the monitoring of the design process was more an interactive process resulting in this doctoral thesis not merely being based on literature and desk research.

During the execution of the survey and during the giving of design support to the design teams, it was clear that a model has to be developed to support architects designing, dimensioning and evaluating demountable building elements. With this model architects can make better informed decisions. Therefore, a model to obtain generic demountable solutions was developed during this study as there are no practical tools at moment.

Figure 1 shows the main structure of this chapter and the relevant input and output. The main conclusions of the conducted survey are found in the following paragraph of this chapter, which is based on an online survey, a workshop and face-to-face interviews. The third paragraph describes the interactive research by design process. First, a short overview is given of the different cases in Paragraph 3.1. Paragraph 3.2 and 3.3 discuss the design process of one case more in detail. The main output of this chapter is an integrated model to design, dimension and evaluate demountable building elements, which is described in Paragraph 3.4. The chapter concludes with a discussion part.
Figure 1: The main structure of this chapter.
To identify why transformable building is rarely applied in the Belgian construction sector, a survey of important stakeholders within the Belgian construction sector was conducted. This study focuses on Belgium as this study was funded by the Flemish government and the advised cases were located in Belgium (cf. Paragraph 3.1). The results could be different for other countries due to the use of other building methods and traditions in a specific country. For example, the application of ‘Design for Change’ could be simpler for countries with a high use of dry building solutions, such as usually in) timber and metal constructions compared to Belgium which has a tradition of masonry buildings.

The data was collected with the aid of a long and short online questionnaire, face-to-face interviews and a workshop. Stakeholders were invited to participate in the long version of the online questionnaire, the face-to-face interviews and the workshops if they already had shown interest in ‘Design for Change’ in the past, for example by attending lectures about the subject. The participants of the short version of the online questionnaire were selected at random. The list of participants can be found in Annexe 2.1: ‘Participants’.

Besides challenges of realising concepts for buildings designed for change in Belgium, the potential opportunities and the necessary steps in order to evolve to transformable buildings were questioned. The inquired people were requested to point out in which building concepts they think the target group of their company would be interested in. In addition, it was examined which time-based principles already are being implemented. Finally, it was investigated if the interviewed persons would be interested in applying ‘Design for Change’.

The online survey consisted of several clustered questions: general and open questions, questions concerning the implementation and demand (at building, component and material level) and questions concerning dismantling and marketing strategies. The participants could skip a cluster of questions if the questions were not applicable for their organisation. This implicates that not all questions are answered by a same number of people. The questions were based on literature which define transformable building concepts, such as described in [6], [7] and [8]. The questionnaire can be found in Annexe 2.2: ‘Questionnaire of the online survey’. Fifty-four people could be achieved in a relatively small time span by the online survey. An interview goes more into depth, but demands more time of the surveyors as well as of the questioned people. Therefore, in this study the number of interviews is limited to five. The advantages, challenges and needs of the design approach were discussed during the face-to-face interviews without having a concrete list of questions. Thirty individuals attended the workshop. The participants of the workshop brainstormed about ‘Design for Change’. The advantages and disadvantages of a workshop lie in between an interview and an online survey in terms of time constraints and depth of the content.
The survey covered 66 independent persons as some persons participated in the online survey and in the workshop or in the interviews. Consequently, this is a qualitative research and not representative for the whole construction industry. Nevertheless, clear insights have emerged for the scope of this research.

The largest group of respondents is ‘manufacturer of building materials and components’ (24%) (Figure 2). Additionally, architects (12%), engineers or consultants (11%) and information centres (10%) replied the survey in high numbers too. Researchers and governmental institutes (both 11%) were consulted too because they can have a broader overview on challenges and solutions to increase the application of ‘Design for Change’. A low interest of contractors in ‘Design for Change’ was discerned (8%). Educational institutes and others, such as a non-profit organisation which promotes co-living, complete the list of participants (both 6%).

The respondents are mainly private organisations (74%). In addition, of the 240 sent short online surveys, only 4 complete and 4 incomplete surveys returned. This low response rate can be explained by a lower interest of the construction sector in general.
2.2. Advantages

2.2.1. Opportunities

All participating organisations of the long version of the online survey responded positively on the yes/no-question: ‘Are there advantages or opportunities associated to the application of ‘Design for Change’?’. In addition, the participants could specify which opportunities they think are related to the application of ‘Design for Change’ without having predefined opportunities. Figure 3 points out the most quoted opportunities for all addressed participants of the long version of the online survey, the workshop and the face-to-face interviews.

Many people (respectively 15 and 23%) consider a reduction of the initial and the life cycle cost as an advantage of designing for change, for example by using second-hand and standardised components as well as other economic advantages. For instance, the application of the design approach could give a boost for innovation and could provide an expansion of the second-hand market. Indeed, economic opportunities are discussed in a recent study by TNO, the Dutch Organisation for Applied Scientific Research [10]. The opportunities of circular economy within the Netherlands are confirmed by figures in this study. The authors estimate that each year an additional 7.3 milliard euro could be gained by implementing a circular economy, which results in 54 000 jobs by reusing waste as resource, even without taking additional spin-offs into account.

In addition, several participants mentioned environmental benefits related to closing the cycle at material- and component level (respectively 17% and 15% of the participants), the reduction of the environmental impact (15%) and the extension of the life span of buildings (13%). As this was an open question, this does not mean that the other participants do not agree with these opportunities, but that they were thinking of other opportunities.

However, during the process of design cases (cf. Paragraph 3.1), demountable building elements were evaluated. The environmental impact of some demountable building elements was high compared to building elements using irreversible connection types. Therefore, in the sixth chapter of this dissertation, a model was developed to evaluate a range of demountable building elements in terms of environmental impact to optimise the design of transformable elements.

Besides environmental and economic benefits, participants also pointed out social opportunities, for example 21% of the participants mentioned the opportunity to anticipate demographic tendencies. Also, individual benefits have been discerned, for example four stakeholders mentioned an easier maintenance of building components, seven persons stated the possibility to adjust dwellings to changing comfort needs of the users and more efficient use of space and six participants mentioned a higher value of real estate.
Figure 3: Advantages of designing for change, cited by the participants of the long version of the online survey, the workshop and the face-to-face interviews. (Number of participants = 53)
2.2.2. Interest

In the second part of the online survey the respondents of the long version were asked if they think the target group of their company is interested in applying transformable principles. A majority reacts on this question positively (64%) and 21% thinks their target group is possibly interested if some obstacles are removed. Only 3% indicates that their clients are not interested and the others (12%) do not know. These percentages align with the demand to apply specific transformable concepts (cf. the following paragraphs). The interviewed people assume that the target group of their company is interested in applying most transformable concepts. A survey made in the Netherlands confirms a high degree of interest of users [11]. In this study more than 70% of the examined residents declare that the space plan of their dwelling does not meet user needs. For this reason 30% of the inquired families would like to move out; additionally 45% would like to stay if the dwellings could be adapted to their needs.

Figure 4 shows the most important figures on the demand of the target group to apply adaptable concepts.

A majority of the participants thinks that the target groups of their company is interested to facilitate changes to the furniture (82%), the layout (86%), the services (70%), the façade (59%) and the loadbearing structure (74%) of a building for example to change the function (89%) and the capacity of a building (96%), above all by the use of multi-purpose spaces (96%). According to the interviewed people the demand to over-dimension services (40%) and the loadbearing structure (32%) to facilitate future changes of the building is rather low.

The participants of the survey give the impression that they are familiar with most concepts, only the use of open-building systems is slightly unknown as 16% indicates that he does not know the meaning of the term.
Our target group is interested to make changes to:

- the furniture
- the layout
- the services
- the facade
- the structure

in order to:

- adjust the comfort level
- adjust the function
- adjust the capacity
- make replacements possible

by:

- reversible connections
- physical decoupling of layers with a different life span
- multi-purpose spaces, by implementing:
  - sliding doors, sliding walls
  - a raised floor, a suspended ceiling
  - an open plan
- a skeleton structure
- over dimensioning:
  - the structure
  - the services

Our target group is interested to reuse building components/products:

- ad hoc
- structured, by the use of:
  - semi-open building systems
  - open building systems
  - open industrialisation

Figure 4: Interest of the target group of the participants’ company in 'Design for Change' concepts, answered by the participants of the long version of the online survey. With n the total number of participants.
Similar questions were asked a second time to know the interest of the participants and their organisations in applying certain transformable concepts. First, the respondents of the long version of the online survey had to indicate if they would like to apply adaptable principles. A large majority answers this question positive (71%) and more than 20% reveals that they already apply certain principles. The others do not know.

The application of certain principles was confirmed during the design process of the cases (cf. Paragraph 3). For example, AREAL architecten had already applied unconsciously several principles in the projects ‘de Vlindertuin’ and ‘de Esdoorn’, such as the use of a skeleton construction, light-weight walls and a modular grid. They applied these principles rather to increase the efficiency of the design and construction process than to facilitate future changes or decrease the environmental impact.

The percentages concerning the current application of transformable concepts are higher than first indicated when more specific concepts are examined during the short and long version of the online survey, with 37% as an average.

Figure 5 shows the most remarkable outcomes of the answers about the implementation of and interest in transformable concepts. They could answer the questions with ‘applied’, ‘planned’, ‘interested’ and ‘uninterested’.

As mentioned before, many organisations indicate that they already implement concepts. For example, they design furniture (52%) and the layout of the building (47%) adaptable to make replacements possible (44%) and to adapt the comfort level (59%), the function (47%) and the capacity (38%), for instance by the use of multi-purpose spaces (55%). More technical concepts, such as the physical decoupling of building layers, which have a different life span, are less frequently applied (21%). As we could expect, open building systems are rarely applied (13%), as well as product service systems (from 11 to 26%).

Most participants are interested to implement certain concepts but they indicate that there are no strategies yet to put the concepts into practice. A high degree of interest in transformability of the construction sector is shown in the results of a similar survey by Paduart [12], where she questioned architects and social housing associations.

There is less interest to over-dimension the structure and the services in order to support future changes in functions and use of the building; respectively 30% and 24% of the people is not interested in applying an additional capacity. In addition, mass production is not a popular concept either, as 27% is uninterested in applying mass production.

All concepts are known by a majority. A few participants indicate they already apply open industrialisation (17%), while in reality this concept has not been applied so far. To increase the application of this concept (which was not mentioned by the participants), a number of rules and agreements have to be formulated applicable for the entire construction sector, concerning among others a modular dimensioning system. By using those general rules, products of different building systems are interchangeable [13].
We are interested to make adaptable:

- furniture
- layout
- services
- façades
- structures

in order to:

- adjust the comfort level
- adjust the function
- adjust the capacity
- make replacements possible

by:

- reversible connections
- physical decoupling of layers with a different life span, by implementing:
  - sliding doors, sliding walls
  - a raised floor, a suspended ceiling
  - an open plan
- a skeleton structure
- over dimensioning:
  - the structure
  - the services

We are interested to reuse building components/products:

- ad hoc
- structured, by the use of:
  - semi-open building systems
  - open building systems
  - open industrialisation

Figure 5: Interest of the participants in 'Design for Change' concepts, answered by the participants of the short and long version of the online survey.

With n the total number of participants.

45
2.3. Challenges

All interviewed people of the long version of the online survey are convinced that the ‘Design for Change’ approach has several challenges. For 44% of the participants of the long version of the online survey, the workshop and the face-to-face interviews an increase of the initial cost is perceived as the main challenge of the ‘Design for Change’ approach (Figure 6). Other studies, such as [14] and [15], confirm that many industry professionals have the impression that the initial investment cost associated to transformable solutions are higher than traditional building solutions. For instance, the cost of transportation and storage can increase the initial financial cost. However, as reuse of building components would be simplified, the price of transformable products can decrease in the long-term. Today, the price of some second-hand buildings products in Belgium is already lower than new products. For example, the price of steel components is only the half of new components [16]. Still, often many new products are cheaper due to the time required to disassemble.

Moreover, the demand of natural resources has increased the last century (from 1900 to 2005) with a factor of 34 due to an increase of the world population and its prosperity. This creates an increasing scarcity of resources. On its turn, prices of resources augment. A realistic prediction expects a further augmentation of material consumption with a factor 3 in 2050 relative to the material consumption in 2000, with further price augmentations as a result. [17]

The second most quoted challenge (mentioned by 17% of the participants) is a limited number of possible configurations. The participants fear that ‘Design for Change’ will lead to uniform, standardised buildings. As a consequence, it is concluded that some respondents do not know the opportunities of open building systems yet. A few respondents (17%) think that neither people in general are familiar with ‘Design for Change’. According to five respondents there is little awareness of the importance of closing the material loops. People are for example not aware of the scarcity of material resources. By constructing buildings designed for change, the material cycle could be closed by recovering building materials for new developments.

Other important challenges are associated to a lack of knowledge. Properties of transformable building elements are not known to designers and demolition contractors lack knowledge to disassemble them. This was confirmed by observing the design processes of the cases. It was hard and time-consuming to find solutions fulfilling all demanded requirements. However, the current knowledge of for example acoustical advisors was sufficient to develop demountable building elements with the desired acoustical performance. Acoustical concepts applied to frame structures are applicable for demountable building elements too. Therefore, to support other architects, in the fifth chapter a model is developed to dimension a range of demountable building elements; it is described how to estimate the thermal transmittance, the load capacity, the fire resistance and impact and airborne sound insulation.

The needed cross-sectoral cooperation of different stakeholders of the construction sector is seen by 15% of the participants as another important challenge. All partners have to work together to construct transformable buildings according to those people. All involved people have to anticipate each other’s decisions: the application of a reversible connection method has for example consequences for the needed acoustical measures. Indeed, after the observation of the cases (cf. Paragraph 3.1), it became clear that all partners, from building owner to technical advisors, have to be convinced of the importance of the design strategy to succeed the successful application. All involved partners had to participate in finding unusual solutions fulfilling acoustical, thermal and fire resistance requirements. Moreover, the building owner of one of the cases was not yet familiar with ‘Design for Change’ and additional sessions had to be planned to inform them about several concepts and the importance of applying them.
Furthermore, according to 15% of the stakeholders the application of certain concepts is in conflict with current legislation. This challenge has been mentioned in several national reports of a large-scale multi-national state-of-the-art report too [18]. For instance, in New Zealand legislation limits the use of reclaimed materials and components without extensive testing to verify their integrity. In addition, a study in Flanders mentioned several other challenges [19]. In this region, it is hard to change a function of a building. Regional plans have to be changed, which demand a lot of time, and when subsidies were obtained for the construction of a building, it is obligatory to repay the amount of money when changing the function of the building. Moreover, standards change over time resulting in (parts of) buildings that do not fulfil all requirements in the future.

Finally, some people mentioned a limited number of transformable products on the existing construction market as a challenge. However, during the observation of several real design cases it became clear that demountable building elements could be designed based on existing products. However, finding those solutions is very time consuming. Therefore, in Chapter 4 it is showed how existing building components and current building techniques are used in an inventive way to design demountable building elements and to achieve a transition between current building practice and a transformable future.
2.4. Answers to challenges

To answer the challenges mentioned in previous paragraph, the participants of the long version of the online survey, the workshop and the face-to-face interviews could propose solutions to increase the application of ‘Design for Change’. There were no predefined answers, but some respondents suggested identical solutions. Figure 7 shows the most quoted answers. In the first place, 32% of the participants propose an (additional) education of the construction sector. Future designers should be educated during their studies in order to have sufficient knowledge about ‘Design for disassembly’, the environmental impact of design choices and the reuse of existing building components. This strategy is addressed in [10] and in the national reports of the large-scale study [18] too. Organising study trips to representative buildings could create awareness.

Furthermore, according to 27% participants of the survey there is an urgent need to make an inventory of the existing knowledge regarding transformable architecture. For instance, information about the ‘best practices’ should be collected and spread amongst the construction sector. In this way, existing designers and other stakeholders could become more aware of the advantages of this design approach and how it can be implemented.

This was confirmed by the design teams of the followed cases (cf. Paragraph 3). The available information is now spread amongst many documents with few drawings, with lots of text and with solutions using products that are not easily available on the market today. Although architects already apply intuitively several building concepts which incorporate changes and/or multi-use of buildings, further spreading basic information about ‘Design for Change’ is necessary. Making the design guidelines accessible for a larger audience, which are described in the second chapter of this dissertation, is part of the solution to inform all stakeholders and to raise awareness.

A design tool should be created too according to 25% of the participants in order to support architects during the complex design process, for instance to evaluate the environmental impact of their design choices. Indeed, KPW Architecten, one of the followed architectural offices during this study (cf. Paragraph 3) wanted to use sustainable materials in relation to their life cycle impact, but they had no access to supporting tools. Therefore, initially they could not achieve this ambition. In addition, the design, the dimensioning and the evaluation of demountable building elements designed during the design process of the cases were very time-consuming which did not facilitate the design process. Therefore, to facilitate this process a script in Visual Basic was developed to design and evaluate demountable building elements taking current legislation into account and to give objective support to designers when they had to make decisions.

Twenty-two respondents report an important role for the government by stimulating real projects, e.g. with the aid of subsidies, higher environmental taxation for building design that does not facilitate change and tax reduction when buildings facilitate change. Some national reports within [18] even mention that without legislative actions, such as taxation and penalty fee, the current market for second-hand components is difficult to be financially feasible and to have a sufficient demand. The authors of the national reports propose to give the product manufactures the responsibility to provide recycling resources for the product at the end-of-life. This responsibility can for example be expanded to provide reuse options for their products too. For example by the use of material passports [10], building materials and components are provided with information about their properties and their manufacturer, with as a consequence that it is easier to oblige a manufacturer to take back his products. In this way, materials passports provide an incentive for suppliers to (re)design their product to facilitate reuse [20].

Moreover, according to 18% of the surveyed people, the general public is not yet aware of the added value of reuse, and should be sensitised. For example, reuse of wood products can be promoted for its architectural aesthetic value. In addition, quantified case studies could demonstrate the benefits.
On the other hand new business models should be developed according to 18% of the participants, for example as response to an increased initial cost. Also in the Netherlands people are aware of the fact that new business models are needed which for example incorporate the shift of the ownership of materials and products from building owners to manufacturers or third parties [21] as the country has a large number of outdated buildings that are difficult to adapt. In addition, the economic crisis had a very high impact in the Netherlands. As a consequence, companies do not longer want to invest in the construction of new buildings that can become quickly obsolete similar to existing buildings. To give the needed boost to the economy, new business models are necessary with an important role for reusing building components [18]. An existing building should be seen as a resource bank of materials to construct new buildings. Material passports can be a solution to develop new business models too. Products, components, systems and buildings can be seen as a service to the users that meets a need of performance [20].

**Figure 7:** Answers to the challenges of the design approach, quoted by the participants of the long version of the online survey, the workshop and the face-to-face interviews.
(Number of participants = 44)

- Sensibilisation of general public: 18%
- Development of new business models: 18%
- Application of an environmental taxation: 20%
- Construction of real projects: 20%
- Creation of a demand and offer platform: 20%
- Sensibilisation of general public: 18%
- Development of new business models: 18%
- Application of generic standardization: 23%
- Development of solutions per building typology: 23%
- Application of an environmental taxation: 20%
- Construction of real projects: 20%
- Creation of a demand and offer platform: 20%
- Sensibilisation of general public: 18%
- Development of new business models: 18%
- Education of the construction sector: 32%
- Inventory of the existing knowledge: 27%
- Development of a design tool: 25%
3. INTERACTIVE RESEARCH BY DESIGN

3.1. Overview of cases

Support was given during a part of the design process of several case studies as exploratory and participatory research. The observation was very enriching as it could be noticed how architects needed support to apply principles of ‘Design for Change’. Four cases were selected and are briefly described in the following paragraphs.

The four selected cases have in common that all have an innovative building client and/or architect. Most of them are leader in his specific field of the market in Belgium and could be easily convinced to apply new design principles. Moreover, the selected cases are very diverse, from new buildings to refurbishments and from dwellings to schools. The selected cases are consequently perfect to design, dimension and evaluate a broad range of demountable building elements.

Only one case study is described more in detail in the main text of this thesis; the other cases are described in the annexes. The WVDM-project was selected as focus point, because no design team was appointed yet and all required design steps had to be made by myself. As a consequence, it was easier to detect the needs to support the design process of a transformable building compared to the other cases.

The case ‘WVDM’ was followed in the context of a larger research project. The administration of the Vrije Universiteit Brussel assigned the TRANSFORM research team to define various design strategies and to assess the long-term environmental consequences in order to select the best refurbishment strategy of the student residences in the green heart of the Etterbeek campus. This case is discussed in the following Paragraphs 3.2 and 3.3.

The second monitored case is a large health care pilot project, called ‘ASTOR’, which is the name of the association between OSAR architects, MPI Oosterlo and OPZ Geel. OSAR architects - together with a team of advisors and designers - want to build innovative residential buildings, in order to reduce costly nursing services by third parties and low impact on the environment. This case and its design process are described more in detail in Annexe 3.1: ‘ASTOR’.

The participation in the design process of the two following cases, ‘HoZe’ and ‘De Vlindertuin’, was part of a larger research project. Beside the VUB research team TRANSFORM, KU Leuven and VITO were involved in this research project, financed by the Public Waste Agency of Flanders (OVAM). The research project was carried out in 2014 with as main goal to examine and develop specific drivers for the implementation of ‘Design for Change’ in practice. Through this research project some building designers, building clients and policy makers were supported in integrating ‘Design for Change’ in their current building- and policy practice.

‘De Vlindertuin’ concerns an extension of the kindergarten and primary school in Mechelen designed by AREAL architecten and is described more in detail in Annexe 3.2. ‘De Vlindertuin’. ‘HoZe’ is a nine stories high apartment building with 64 dwelling units constructed in 1961. The architect’s office KPW Architecten has been commissioned to design a fundamental upgrade of the building. This project is described more in detail in Annexe 3.3: ‘HoZe’.
3.2. Case ‘WVDM’

The ‘WVDM’ project considers the assembly of 352 student residences located in the green heart of Etterbeek campus of the Vrije Universiteit Brussel. The student residences were constructed in 1973 and were extended with additional housing units in 1978. Residences of both construction periods are still in use today. However, they are outdated and no longer comply with contemporary regulations [22]. With the intent to tackle the university’s expansion, a large construction project has been planned on the campus. Among other things, this project includes the establishment of new research, education and housing facilities. Consequently, the 352 existing residences have become obsolete and are threatened by demolition. However, the residences have a specific historical value. Not only do they epitomise the turbulent foundation process of the Vrije Universiteit Brussel in the early seventies, this is one of the few examples of the application of the Swiss construction system ‘Variel’ by the Belgian modernist architect Willy Van Der Meeren. Van Der Meeren adopted this modular construction system because the booming standardisation and prefabrication methods of the time allowed him to quickly install a large assembly of residences. Still in use today, the residences have become a renowned example of the industrialised architecture that flourished worldwide during the seventies. Moreover, Van Der Meeren did not apply this construction system uncritically. Carefully shifting and stacking the individual concrete modules of the system, he created a village-like assembly.

Because the student homes carry an important historical value, strategies have been defined as an alternative to the demolition of these heritage residences. A refurbishment related to new functions is formulated as an alternative option. The Vrije Universiteit Brussel considers new more commercial and public functions as a possible destination of the student residences, such as a news agent’s and an information centre. A transformable design is preferred for these functions because in all probability new (smaller) refurbishments will follow in the near future to respond to a shifting market and changing trends.

WVDM

Status: Refurbishment  
New function: commercial, public functions  
Number of floors: 1 or 2  
Owner: VUB  
Original function: student houses  
Original architect: W. Van Der Meeren

© Galle
3.3. Design process of ‘WVDM’

Just as in the ‘HoZe’ case (cf. Annexe 3.3: ‘HoZe’), the TRANSFORM research team was involved in the project of the student residences ‘WVDM’ at an early stage, before an architectural firm was selected. The building owner, the VUB, still has to make several strategic choices before an architect can be appointed. Our task was to map out and evaluate potential scenarios for the student residences, from demolition to refurbishment, in terms of financial and environmental impacts. The opportunity was used to propose and evaluate an adaptable refurbishment as possible scenario too. In this way a basis could already be created for using transformable concepts in this project. The VUB was mainly interested to give a commercial or public function to the student residences. Therefore a transformable design is preferred to respond to shifting markets and changing trends.

It demanded a lot of time to design a limited number of building elements fulfilling all requirements demanded by legislation, from thermal requirements to a sufficient fire resistance. Therefore, the necessity grew to develop a tool that supports this process. During this case study a tool was elaborated that estimates the minimal thickness of the different functional layers of a building element in order to fulfil the demanded objectives as well as perform the environmental evaluation (cf. Annexe 1: ‘Manual of decision-supporting tool’).

In addition, the results of the environmental life cycle impact of some demountable building elements were not persuasive yet. For example, the refurbished external wall element using irreversible connection types has a lower impact than the designed demountable element for all evaluated scenarios, due to a thick layer of OSB for obtaining an equivalent fire resistance to plaster and sand-lime bricks (Figure 8). Paduart revealed that it is possible to design a transformable façade with environmental benefits, for example when a thermal upgrade of the façade is taking place every 15 years [12]. Therefore, to have benefit of using demountable elements, the design of the demountable element should be improved. Otherwise, a strategic decision is needed by combining demountable with irreversible connected building elements in the same building project to limit extra environmental burdens. A demountable proposal can nevertheless be chosen for other reasons, such as a limited construction process.

Other designed demountable elements had a lower environmental impact compared to a design with irreversible connection types. For example, Figure 9 shows the results of the evaluation of the roof variants.

The demountable roof element has a ballast layer of gravel to fix the EPDM waterproofing foil and the slope of polyurethane board. In addition, the demountable roof contains a thermal insulation layer of mineral wool between wooden battens, a polyethylene foil as vapour barrier and airtight membrane and plywood as ceiling finishing. The irreversible version has a bitumen foil as waterproofing, a polyurethane board as slope, a polyurethane board as thermal insulation layer between timber battens, a polyethylene foil as vapour barrier and gypsum plasterboard as ceiling finishing. Both variants reuse the existing concrete floor slab with a T-section as loadbearing structure. The thermal insulation layer is in both cases placed between timber battens at the inside of the structure to retain the appearance of the original building as much as possible without creating thermal bridges. The timber battens create a small void for technical services between the insulation and finishing layer.

The demountable roof element has a lower impact than the irreversible version in the short and long term. When more refurbishments are planned in the future the positive difference will further increase.
Figure 8: The environmental impact of an external wall element using irreversible connection types (a) and of a demountable external wall element (b).

With IE as initial environmental impact, LE\textsubscript{min} as life cycle impact with no refurbishments, LE\textsubscript{aver} as life cycle impact with an average number of refurbishments, and LE\textsubscript{max} as life cycle impact with a maximum number of refurbishments during 60 years.
Figure 9: The environmental impact of a roof element with irreversible connection types (a) and of a demountable roof element (b).

With IE as initial environmental impact, LE\textsubscript{min} as life cycle impact with no refurbishments, LE\textsubscript{aver} as life cycle impact with an average number of refurbishments, and LE\textsubscript{max} as life cycle impact with a maximum number of refurbishments during 60 years.
3.4. Decision-supporting model

3.4.1. Introduction

Five main design steps were identified after the observation of the design process of the four cases. The design steps are described in Annexe 3.4: ‘The ideal design process’. By following these main steps the design process of a transformable building can be executed more smoothly in the future.

During the supervision of the cases, it became clear that there are no standard transformable solutions fulfilling all requirements and that they cannot be designed either. Each case is characterised by such a variety of boundary conditions and requirements that it is impossible to develop standard solutions per function, from dwelling to office building, and per status - new building and refurbishment. On the one hand, there are structural, acoustical, and fire resistance requirements, which depend on a variety of parameters, such as the function, the span, the height, the chosen materials and the mass of the building. On the other hand, there are boundary conditions related to the site and local rules. In addition, members of the design team, the building owner, the future inhabitants and contractors have preferences in terms of applied finishing materials, the degree of finishing, the structure used, the detailing, the total cost and the construction time. Some design teams are interested in a range of different building materials with as a consequence a range of building elements had to be designed, dimensioned and evaluated.

Moreover, often there was not enough knowledge about other properties of the proposed demountable building elements, such as thermal and acoustical performance, structural security and fire resistance. The design process could be executed smoother if more knowledge is available about the performance of demountable building elements.

In addition, the results of the environmental life cycle impact of some demountable building elements were not persuasive yet. To have benefit of using demountable elements, the design should be improved. However, the design and assessment of a demountable element take a lot of time, which makes iterative improvements less realistic in practice.

To tackle these design problems a decision-supporting model for a user-friendly tool for designers is developed in this doctoral research. The design process is already so complex that supporting design tools are more than welcome, especially if transformable requirements are demanded in addition to requirements obliged by legislation, which was mentioned in the survey of Belgian stakeholders too. An integrated tool can help designers configuring and improving building elements and comparing them on the basis of their qualities, such as the environmental impact as well as properties in terms of building physics. This integrated tool should support design teams to choose materials and to design structural detailing and simultaneously get an insight in the long-term consequences of their design decisions. This parametrised tool has to take different physical parameters into account, such as the dimensions of a component and the replacement frequency and environmental parameters, such as included impact categories.

Also in Belgium they are working on the development of a decision-supporting tool. The KU Leuven and the research institutes VITO and WTCB are collaborating to develop a user-friendly web tool that evaluates the environmental impact of building elements, called the MMG-tool [23]. A first public version is expected at the end of 2016.

The Swiss “Bauteilkatalog.ch” is a web tool that is already available [24]. This simulation tool calculates the environmental impact of building elements assembled by users. For example, a user defines the thickness and type of insulation materials of predefined element variants.
However, often the freedom of a user when using the available tools is limited to the choice of insulation material and its thickness. In addition, often the functional unit of the evaluated building elements is fixed [23]. This means that all available building elements have equivalent properties. In general, the building elements have an equal thermal performance, which is based on the U-value. Often other important properties are neglected, such as the demanded fire resistance. According to the ISO 14044 standard [25] the definition of a functional unit is needed to guarantee an objective comparison between different design options. But it hinders architects to design a building element for a specific context which is possibly different than the fixed functional unit. Another drawback of current tools is that mainly building elements with irreversible connection types are evaluated.

Ideally, transformable design solutions should be included next to irreversible connected building elements and future refurbishments should be taken into account by including several scenarios. The model of the tool which is presented in this doctoral thesis could therefore be an interesting extension of current tools and tools in development. The goal of this decision-supporting model is to assist designers in making sustainable choices during the preliminary design stage in terms of building methods and materials of the main functional layers, e.g. the structural, finishing and insulation layer, instead of only focusing on insulation materials. This model has the ambition to allow designers to design, dimension, evaluate and compare large amounts of elements. The process should therefore be almost entirely parametrised to make it possible to assemble numerous variations.

The aim of the proposed model is to make it possible for designers, engineering firms and other interested people to assemble and evaluate building elements based on components that are available in a database without making it more complex and demanding more time than current tools. This is achieved on one hand by systematically increasing the complexity of the design and on the other hand by fixing the value of several parameters. For example, the considered life span of a building is standard 60 years, but can be adapted if needed. In addition, material suggestions are given for the other functional layers on the basis of the previous choices without showing all possibilities from the start as this could be overwhelming for users.
3.4.2. Method

The decision-supporting model was developed, tested and improved during the design process of the cases in order to facilitate the design, dimensioning and evaluation of demountable building elements. In the first instance, a solution was searched intuitively and separately for each new problem posed during the design sessions of the cases. For example, one of the designers asked to evaluate several designed demountable building elements in terms of environmental impact and to compare them with several traditional variants; for another case several designed building elements had to be dimensioned in terms of thermal performance. Each time a solution was found to one specific problem. But, by tackling each problem independently, precious time was lost. Each time, a solution had to be found from scratch. However, the problems could be grouped, just as the solutions. Gradually, a structure became clear in the possible questions of the design teams and in the solutions too, which resulted in a unified, generic model. This model can not only solve problems of the cases, but can solve many more problems during the design, the dimensioning and the evaluation of many other demountable building elements.

Figure 10: The five main steps of the decision-supporting model.
Figure 10 visualises the thinking process behind the model in the form of a flowchart. In the context of this study a possible implementation of the model was developed (cf. Annexe 1: ‘Manual of decision-supporting tool’). An interactive user-interface was scripted with Visual Basic in Excel software to facilitate the detailing process of the case studies. The model consists of 5 main steps. The methods behind those steps are described in the following chapters of this thesis.

**STEP 1:** During the first step the user has to enter several project parameters, such as the function of the building (i.e. office, school,..), the status (new building or refurbishment) and the building method (conventional (using irreversible connection types), demountable or a combination).

**STEP 2:** Next, a functional unit is defined by case dependent parameters, such as the function and the height of the building\(^1\), in order to make an objective comparison of several building elements possible in the future over a time span of 60 years. The tool will search the requirements prescribed by legislation in terms of fire resistance and thermal and acoustic performance based on those parameters (cf. Annexe 5, 6, 7). The user can change the performance of the functional unit if wanted.

**STEP 3:** Subsequently, a user can ‘assemble’ a building element. First, he/she has to select which part of the building he/she wants to assemble: an internal, partition or external wall, a ground or suspended floor or a flat roof. The tool now will visualise all possibilities for each functional layer of the building element (e.g. wall finishing, structural layer, insulation material and exterior cladding) and the user can select his/her preferences. The options depend on the building method chosen in the first step. The possible finishing components depend on the class of reaction to fire performance too. Some options depend on other functional layers and are therefore not initially visible. For each functional layer, it is checked how the functional layer is connected to other layers. A very broad spectrum of combinations is possible as the tool is parametrised.

The background knowledge is documented in the fourth chapter of this doctoral thesis. By this information the tool knows which functional layers and connections are necessary to make a realistic building element\(^2\).

**STEP 4:** After selecting the main functional layers through the interface, the software gives an indication to the user of the required thickness of each functional layer to achieve the demanded performance of the functional unit by verifying the properties of the element. As a consequence, it is guaranteed that relevant equivalent solutions will be compared. Therewith, the script takes notice of products available in practice, standards to calculate for example the thermal performance of an element, literature, rules of thumb and information obtained from the observation of the cases, described in the fifth chapter of this dissertation. For example, dimensions and properties of products available on the market today are taken into account. After defining the thickness of each functional layer, the mass is calculated based on the density of the chosen component. If needed, the user can always adapt the output after each step, for example if a thicker finishing is desired for one reason or the other.

**STEP 5:** Finally, the environmental impact of the assembled building element can be calculated based on the obtained masses, including maintenance, repair and replacements and according to several scenarios (no future refurbishments, an average number or a maximum number of refurbishments). The results are divided per functional layer and per life cycle stage. If the results are not convincing, a new building element can be assembled over and over again in order to lower the environmental impact. This step is well-documented in the sixth chapter of the thesis.

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\(^1\) The height of the building will influence the demanded fire resistance.

\(^2\) The choice of building elements was based on the cases and therefore no pitched roofs are included yet.
4. DISCUSSION

The conducted survey covers 66 independent persons. Consequently, this is a qualitative research and not representative for the whole construction industry. Nevertheless, several outcomes are confirmed by other international studies, such as [10], [11], [14], [15] and [18]; as a result it is assumed that most outcomes are valid for the entire Belgian construction sector.

During the observation of the design cases, it was made clear that there is in practice no time to experiment with the design of new building components and to make prototypes. The designed demountable building elements have to be based on existing building products and techniques to gain time. In addition, it became clear that demountable building elements could be designed based on existing products, but that finding those solutions is very time consuming. Therefore, in the fourth chapter of this dissertation it is showed how existing building components and current building techniques are used in an inventive way to design demountable building elements and to achieve a transition between the current building practice and a transformable future.

One of the aims of applying ‘Design for Change’ is to reduce the environmental impact of the construction sector. However, during the design process of several cases, a high environmental impact was observed for some designed demountable building elements compared to building elements using irreversible connection types. Therefore, in Chapter 6, a model was developed to evaluate a range of demountable building elements in terms of environmental impact to optimise the design of an element. The quantitative evaluations give architects an objective basis and argumentation for their design choices.

At the moment, designing, dimensioning and evaluating demountable building elements is very time-consuming which does not facilitate the design process. For example, a lot of time was needed to evaluate the environmental impact of a design resulting in a design team opting for other solutions in the meantime and results not being relevant anymore.

Therefore, a decision-supporting model was developed in this dissertation incorporating the findings of the different chapters. A rudimentary version of this model was scripted in Visual Basic to support the design teams of the cases in order to give objective support when they had to make decisions taking current legislation into account.

Although according to 44% of the respondents an increased initial cost is a challenge to apply ‘Design for Change’, this study does not focus on the evaluation of financial impacts of demountable building elements for several reasons. For example, one of the followed design teams mentioned that designers are capable in estimating initial and life cycle costs, but that they are not capable to evaluate the environmental impact of their design proposals. In addition, several building owners emphasised the importance of the environmental impact of buildings. Moreover, another member of our research team, Waldo Galle, is currently analysing the life cycle costs of ‘Design for Change’ [26]. During his doctoral research he developed a tool to calculate the life cycle costs of ‘Design for Change’. This tool could be used as a starting point to extent the tool developed in this research to assess financial costs next to environmental impacts.
PUBLICATIONS


REFERENCES


