A brief state-of-the-art of ‘Design for Change’ approaches is presented in this chapter to introduce the context of the key principles that are summarised in the second section of this chapter.

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

Today, several publications, such as [4], [5], [6], [7] and [8], describe design guidelines and a few of them, such as [4] and [8], present practical examples of how ‘Design for Change’ can be implemented and elaborated, but the link with the building practice is often limited to several detailed drawings. Moreover, often the available information is scattered over several documents and practical information is snowed under with theoretical background information. In addition, most publications are not always useful and easy accessible. It is consequently difficult for a designer to find the correct or detailed information.

To close the gap to build in a transformable way, a range of leaflets are therefore developed in this chapter explaining the main ‘Design for Change’ guidelines and giving several practical solutions. In this way, a summary is given of the necessary knowledge in applying key principles of ‘Design for Change’. These guidelines offer a translation of the theoretical framework of ‘Design for Change’ into practical key principles and examples that can be consulted by architects and designers. It was important not to overload the reader with information, but to find an equilibrium between clear and sufficient information to encourage designers applying the key principles. Consequently, the description of a key principle is limited to two pages with comprehensive explanations, clear drawings and inspiring pictures of applications. The designer can use the references on the leaflets for more and detailed information. To ensure the use of the leaflets by architects, the leaflets were refined during the advice process of two building projects.

Figure 1 shows the main structure of this chapter with the relevant input and output. After this introduction, a brief state-of-the-art of ‘Design for Change’ approaches is presented found in practice and in research, based on literature. In addition, shortcomings of the current available information are stated, based on the experience of the design teams consulted during this study, cf. Chapter 3. In the second main part of this chapter, a summary of the leaflets of ‘Design for Change’ is given in order to provide readers with sufficient knowledge of ‘Design for Change’ to read the following chapters. For example, the key principles are being used in Chapter 4 to evaluate propositions in a quantitative way. The leaflets - taking into account the shortcomings of the current available information mentioned by the design teams - are mainly based on literature (cf. Paragraph 2) and a first preliminary research project for OVAM [21]. The design teams commented on a first version of the leaflets with improved leaflets as a result. The feedback from builders, and engineering and architectural offices involved in the projects led to adaptation of some of the proposed principles. For example, the design teams emphasised the importance of an attractive layout and of clear drawings that explain the principles to increase the comprehensibility. This chapter concludes with a short discussion section.
Figure 1: The main structure of this chapter.
In the last decennia guidelines and principles were analysed, summarised and documented and assessment tools developed in order to support architects in the design of adaptable, demountable, reusable and recyclable buildings. Nordby (2009) gives an overview of the principal publications written about qualitative guidelines to facilitate material resource efficiency through reuse and recycling in her doctoral thesis [4]. Bjørn Berge (2009), Philip Crowther (2003), William Addis and Schouten (2004) and Elma Durmisevic (2006), as well as Scot Fletcher (2001), Chris Morgan and Fionn Stevenson (2005), Paola Sassi (2002), Catarina Thormark (2001) describe and classify detailing principles that allow reuse and deconstruction, which is the process of carefully taking apart a building with the intention to maximise reuse or recycling of components and materials and to minimise landfill [4], [5], [6], [7], [8], [9], [10], [11], [12]. Those detailing principles have to be checked with other physical building constraints, such as wind tightness, and do not give an absolute guarantee of reuse in the end. Some of these publications include methods to assess the transformability of a building or element [11], [12]. For example, Elma Durmisevic (2006) presents ‘the Transformation Capacity Tool’ - a framework for assessing the transformation capacity of built structures in her thesis [8].

A few publications, such as [4], [8] and [10], present practical examples of how the guidelines can be implemented and elaborated in practice, but the link with the building practice is often limited to several detailed drawings. Moreover, the design teams which were consulted during this study, cf. Chapter 3, state that the available information is scattered over too many documents and that practical information is snowed under with theoretical background information. In addition, most publications are not always useful and easy accessible. It is consequently difficult for a designer to find the correct or detailed information.

Although the presented assessment tools give insight into the transformability of buildings and their elements, specialised knowledge is required to handle the tools and to implement its findings in the design of a building.

Preliminary research conducted in the ‘Transform’ research team clarifies that conceptual and technical solutions can be developed in the context of ‘Design for Change’ for a variety of building types and functions, ranging from temporary structures to more permanent ones. For example, Caroline Henrotay (2008) designed and prototyped adaptable construction kits for application in transformable shelters in an international emergency context [13]. The components of this system can be combined into numerous shelter typologies of variable sizes. Other doctoral theses of the Transform group assessed the environmental and financial life cycle benefits and drawbacks of transformable solutions [14], [15]. Debacker (2009) assessed the environmental benefits of a multi-use construction kit for transitory dwellings and infrastructure for foreign relief situations [14] (Figure 2). Paduart (2012) explored the integration of ‘Design for Change’ approaches into the refurbishment process of buildings [15]. She developed an evaluation methodology to assess the environmental and financial life cycle impacts that can be related to the reuse of building components.
Nevertheless, the implementation of reversible detailing methods and reusable components in full scale realisations, such as the Cellophane House designed by Kieran Timberlake Associated [16], remains limited. Therefore, the Transform research team is exploring several valorisation projects, such as the DynamicWall project, a project funded by Innoviris [17]. In this research project, the feasibility of adaptable and reusable wall systems was explored for the residential building market in Brussels. Innovative wall solutions were designed, prototyped and tested, through extensive (dis)assembly sessions, vertical impact and acoustical performance testing, and finally, implementation in a real demonstrator project in Brussels.

In addition, many Belgian and European policy makers are convinced of the opportunities of transformable design principles and support research to valorise transformable principles [18], [19]. For example, the Public Waste Agency of Flanders (OVAM) - charged with the protection of people and environment against harmful effects of production, usage and control of waste – developed a strategic plan towards 2020, including a sustainable waste and material plan with a life cycle perspective. OVAM wishes to shift from ‘waste management’ to ‘sustainable material management’, including transformable building principles as one of the five key principles in order to realise their policy plan. [20]
3. **KEY PRINCIPLES OF ‘DESIGN FOR CHANGE’**

3.1. **A subdivision of key principles**

In this section it is illustrated how ‘Design for Change’ can be implemented in practice by describing several principles that are fundamental for this design approach.

A range of leaflets were developed explaining ‘Design for Change’ guidelines and giving several practical solutions, developed in the context of a research project financed by OVAM on behalf of the Flemish government in 2014 in collaboration with VITO (Flemish Institute for Technological Research) and KU Leuven. The summarized key concepts, the framework, clarification and figures included in these leaflets – mainly based on literature (cf. Paragraph 2) and a first preliminary research project for OVAM [21] - clarify ‘Design for Change’ principles so that architects get a better understanding of how to implement them in a daily context.

This research project was carried out in 2014 with the aim to involve architects, building owners and policy makers in the first implementation steps of transformable building design in the current construction and policy practice. Next to the development of practical leaflets with the key concepts, a user friendly evaluation tool and a brochure with terminology of Design for Change concepts [22], also transformable design advice was given to the project teams of two ongoing construction projects. The leaflets and the evaluation tool were based on the outcomes of a previous research project, which explored how transformable building design can be implemented and assessed for social housing at element, building and urban level [21].

Three scale levels described in the preliminary study (urban, building and element level) were further elaborated in practical leaflets, dealing with ‘Design for Change’ guidelines. Each scale level was subdivided in three topics, based on the first research study [21]: ‘Interfaces’, ‘Components’ and ‘Composition’. The design guidelines concerning ‘Interfaces’ consider the interaction of different components, e.g. the connection between a gypsum plasterboard and a metal stud. The topic ‘Components’ covers guidelines about the design and material use of components, e.g. the durability of a wooden component. Finally, the topic ‘Composition’ contains guidelines about the composition of components in an element, e.g. the way of layering of a façade assembly.

The leaflets concerning the ‘element level’ were developed in the context of this Ph.D. dissertation. The structure and layout of the leaflets at ‘urban’ and ‘building level’ are based on the leaflets at ‘element level’ and all leaflets can be consulted freely on the OVAM-website [23]. Table 1 gives an overview of the different design principles at element level. The subtopics of ‘Interfaces’ (Reversibility, Simplicity and Speed), Component (Compatibility, Durability, & Manageability), and Composition (Independence, Pace-layering & Prefabrication) are being discussed in the next paragraphs. The following paragraphs give a summary of the leaflets in order to provide readers with sufficient knowledge of ‘Design for Change’ to read the following chapters.

The usage of the design guidelines will help designers to evaluate their design decisions. This qualitative assessment shows transformable properties of a design proposal and it highlights the potential of the existing situation. Additionally, this qualitative advice aims to give insights in how to improve the design in terms of transformation capacity and it indicates simultaneously the current limitations of transformable building in practice. In the future this could perfectly be carried out by someone else who is familiar with the key principles. The evaluation of the observed cases (cf. Annex 3.2: ‘De vlindertuin’ and 3.3: ‘HoZe’) can be used as examples. If a preliminary design does not fulfill the design guidelines, the design can be improved with an iteration process.

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1 The key concept ‘Reuse’ included in the leaflets is replaced in this Ph.D. dissertation by ‘Manageability’ as using second hand components is not a key principle that is necessary to design transformable building elements, but more a strategy to lower the environmental impact itself. The manageability of a component, which is necessary to facilitate reuse of building components was not yet included in the design guidelines and was added to the key concepts.
Table 1: Overview of the subdivision of design principles for ‘Design for Change’ at element level.
The figures are partly based on [21].

<table>
<thead>
<tr>
<th>Interface</th>
<th>Component</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversibility</td>
<td>Compatibility</td>
<td>Independence</td>
</tr>
<tr>
<td>Simplicity</td>
<td>Durability</td>
<td>Pace-layering</td>
</tr>
<tr>
<td>Speed</td>
<td>Manageability</td>
<td>Prefabrication</td>
</tr>
</tbody>
</table>
3.2. Interfaces

3.2.1. Reversibility

**Principle**
“Reversible connections are connection types that can be undone without damaging the components they connect.” [22]

**Benefits**
The reversibility of connection types strongly influences the feasibility to reverse connections and demount each component without damage [22]. Components can only then be efficiently reused or sorted and recycled.

**Examples**
To support future reuse of building components reversible mechanical fasteners, such as bolts and screws, or even clips and Velcro straps, are preferred. Figure 4, mainly based on [10], gives an overview of the evaluation of some common reversible and irreversible connection types. Two components can also be connected reversibly without a fastener. For example, Lignatur’s floor panels are attached by tongue and groove sections (cf. Figure 3). Figure 5 shows that ‘Clickbricks’ are connected reversibly by the use of clips.

A reversible fastener can, but does not have to be reusable. Fasteners, such as glue and welding make a non-destructive disassembly almost impossible. Other fasteners, such as lime mortar and nails can be removed, but the deconstruction process is rather labour intensive and therefore not preferred.

**Attention point**
When using reversible connections, often air gaps are created between components and layers. These gaps are Conventionally sealed by mortar, silicone glue or plaster to provide the demanded air- and water tightness of an element, which is not recommended to encourage reuse of components. Therefore, often extra measures are necessary to provide the demanded air- and water tightness (cf. Chapter 4).
Figure 4: Several common connection types, ordered according to their reversibility, mainly based on [10]. Figures are partly based on [15], [24].
3.2.2. Speed

Principle
The key principle ‘Speed’ focuses on a fast and easy assembly and disassembly of building components.

Benefits
The faster and easier building components can be assembled and disassembled, the higher the chance the components will be demounted and reused at the end of a use cycle as the feasibility will increase.

Example
By making connections visible and physically accessible, workmen can easily and safely reach them, increasing the ease of assembly and disassembly (Figure 6: right). If a fixing is behind a component and therefore not accessible, much more time will be needed to remove it [10]. In addition, space around the connection is needed to manoeuvre with appropriate tools and to adapt or remove components. By using a standardised and limited range of connectors the less tools are needed, the time and effort to switch between tools and the complexity of the (dis)assembly process are reduced [25]. The assembly time can further be speeded up by using dry connections, e.g. using screws instead of mortar - which has a long drying time. Moreover, by limiting the number of connections to a minimum, the assembly and disassembly process can be reduced (Figure 6: left). Figure 6 visualises several measures to speed up the assembly and disassembly process.

Attention point
However, while fewer components of larger size will minimise the number of connections to assemble an element, the reuse potential of a component can become lower [25].

Figure 6 visualises several measures to speed up the assembly and disassembly process.
3.2.3. Simplicity

Principle
The key principle ‘Simplicity’ focuses on simple fixings between components. The use of simple, commonly used connection methods facilitates the ease of disassembly.

Benefits
Complex fixings, which can often only be implemented by professional people with specialist skills, also require specialists in the long term to be dismantled. Also, a high complexity of assembly work and complex connection methods, can make the (dis)assembly process inefficient [25], resulting in increased labour costs. Besides, simplicity in the material selection offers additional advantages. First, fewer material/waste fractions when deconstructing the building simplify the sorting process. Furthermore, when the quantities of sorted material fractions increase, their marketing potential and reuse potential increase as well [4].

Examples
Figure 7 shows several simple connection methods that can be mounted and demounted with standardised tools, based on pictures of [24]. The provision of realistic tolerances between the components will allow movement and will simplify the disassembly and reassembly process. Generally, the larger the construction element, the more space is required for deconstruction and removal [10]. Readable building methods are preferred, which give access to information about material components and their reuse potential so a layman can ‘read’; for example, a loadbearing structure or how he can have access to the services. In addition, homogeneous materials are preferred and secondary finishes should be avoided as this can facilitate the reuse and recycling process [4].
3.3. Component

3.3.1. Manageability

Principle
A manageable component is a component that is easy to handle by one worker.

Benefits
A small format facilitates self-building and local reuse and it eases handling and transport [26]. In addition, the reuse of building components is more likely when components are designed in such a way that architectural freedom is given in a second service life. A high manageability of the components will enable the components to be reused for new purposes. For example, if components are too large and specialised, the components can almost only with ease be reused in a similar building, whereas small to moderately sized components give freedom of design [4].

Examples
Small scale and lightweight components give more architectural flexibility to solve functional as well as structural challenges (Figure 8). Furthermore, differing dimensions for height, width and length, and also different connection methods, make a component highly adaptable and eases variations in expression and detailing and in architectural styles [26].

Figure 8: Several building components, ordered according to their manageability.
3.3.2. Durability

Principle
Durable components are components that last long and that can be readily recovered without damage due to repeated transport and intensive (re)use of building components.

Benefits
Reuse of building components is only feasible if their materials allow repetitive reuse. Components can only endure repeated reuse if durable materials are used [10]. However, materials with low initial impacts do less require a long lifetime in the same way as high impact materials [4]. One can say: the higher the initial environmental and financial impacts, the higher the necessity to reuse a component, cf. Chapter 6.

Example
When, among others, the connection method is reversible and the components are detailed taking physical building requirements into account, durable building components have a great reuse potential due to their high impact resistance after repeated assembly and disassembly processes. In this thesis, the key principle ‘durability’ of a component is evaluated by the technical service life of a component, which is based on literature, such as [27], [28], [29] and [30]. Components that are easily maintainable and that have a high technical service life are preferred, such as bricks, gypsum fibreboard and cellular glass (Figure 9), without overlooking other boundary conditions, such as aesthetic quality, cost and weight. Other characteristics, such as the possibility to recover a component without damage, are important as well in terms of durability, but are more difficult to assess.

Figure 9: Materials ordered according to function and technical service life.
3.3.3. Compatibility

**Principle**
Compatible components of building elements are designed and dimensioned in accordance to a dimensional standard, to support a better interchangeability of components within a building system [22].

**Benefits**
Compatible components give more architectural freedom in the second life of a reclaimed building component [26]. The goal of developing compatible building systems is to generate numerous unique configurations, instead of using closed building systems. Closed building systems were widely used in the post-war period to rebuild parts of Europe, but resulted often in uniform and monotonous buildings [4]. Closed building systems were mainly designed for one specific project and resulted in a limited number of large construction parts [31]. An open building system has a different starting point: a series of construction elements is designed that can afterwards be combined in multiple configurations or buildings [14], [31]. Figure 11 illustrates these concepts, based on figures of [32]. Compatible components can be replaced by similar or new compatible components, hence, extending the life span of buildings.

**Examples**
Compatible components can be designed with the aid of a fractal model. An example of a fractal model is the model of the Hendrickx-Vanwalleghem design strategy [33]. This form and dimensioning system uses doubling and halving series and is therefore a simple design tool to ensure full compatibility of components. This way of thinking is called ‘open industrialisation’, wherein construction elements, which can be produced by different manufactures, are based on the same design rules and can be combined to construct a variety of projects [34]. The selected base dimension in this research is 10mm as analysis of existing building products by Paduart (2012) showed that many products are based on this unit [15]. Figure 12 shows this fractal model, designed by OpenStructures, which is used to design, among others, kitchen units (Figure 10).
Figure 11: Building systems versus compatibility.
Figures are based on [32].

Figure 12: A fractal model.
© OpenStructures [24]
3.4. Composition

3.4.1. Pace-layering

Principle
Pace-layering is a design principle to organise components of a building element with a similar expected technical and functional life span into layers. The technical life span is related to the maintenance, repair and replacement rates of a particular building component. The functional life span of a layer is related to the refurbishment rate of an entire or a part of a building element. For example, an exhibition place needs a different internal partition. The layers are organised in such a way that a layer with a shorter life span is easier to reach, maintain and adapt than a layer with a longer life span [22].

Benefits
Building components featuring in façades, walls, floors, etc. all have other functions and all have different replacement rates. Most components need repair, replacement and/or refurbishment during the building life span, for example, due to new aesthetic trends or evolving technical requirements. These processes may generate unnecessary waste because removed components are often bonded to other components, meaning that these adjacent components must be removed as well [10]. Therefore, the pace-layering of building elements into physically separated functional and technical layers - with a similar lifespan - support lower waste production during replacement and refurbishment processes. By pace-layering, components with a shorter technical life span can be replaced without having to remove the entire building element [14].

Examples
Components have to be clustered into layers with a similar life span and function. According to Brand (1994) the main layers of a building are the ‘Site’, ‘Structure’, ‘Skin’, ‘Services’, ‘Space plan’ and ‘Stuff’ [35]. Those main layers can contain several independent sub-layers each with a different function. For example, the ‘Skin’ contains an external finishing, a waterproof covering, an insulation and a structural layer, a vapour barrier and a wall finishing.

Those layers are organised according to the expected functional and technical life span of the components. Layers with a shorter technical or functional life span are placed closer to the surface to facilitate access. In addition, layers are physically separated to enable replacement without disruption or damage to other layers [10] (Figure 13). This does not mean each layer has to be assembled separately; to increase the construction process, a structural layer may be pre-assembled in elements with insulation and finishing with the ability to take a functional layer apart [14].
Figure 13: Several examples of a wall, ordered by degree of layering.
3.4.2. Independence

**Principle**
A component is independent if it can be removed without having to remove adjacent components.

**Benefits**
Independent components contribute to a simplified disassembly and transformation process [8]. The independence of components is crucial to remove components to maintain, repair or replace a component without impinging or removing other components [15]. In addition, dependent components create longer assembly processes and therefore longer disassembly processes too [8], which should be avoided to increase the reuse potential of the components.

**Examples**
The independence of a component is affected by its geometry, which is closely related to the connection type. The geometry of a component can be categorised into two main groups: open and overlapping geometries (Figure 14). Overlapping geometries are less suitable for disassembly, as elements can be disassembled only in one direction. Components with open geometries can be (dis)assembled synchronous with other open components, which can limit the duration of the (dis)assembly process to a minimum. [8]
3.4.3. Prefabrication

**Principle**
Prefabrication of building parts involves the off site assemblage of building components into larger packages from materials to modules.

**Benefits**
Prefabrication does not necessarily increase the transformability of an element, but it can play an important role if principles such as simplicity and disassembly are incorporated. By pre-assembling components, not only the efficiency of the construction process on site is increased [36], but also elements can be faster disassembled and re-assembled to anticipate changing needs during the use of a building (Figure 15). In addition, fabrication processes can offer greater precision and better value, which results in higher conformability and therefore more possibilities to reuse components in other projects. Furthermore, prefabrication can decrease the financial life cycle investment and the environmental impact. For example, studies show that prefabrication generates 35 to 100 percent less waste than on site construction and that it lowers air and water pollution, dust and noise [37].

**Examples**
The level of prefabrication is characterised by the completeness of a building element. For example in the case of an external wall, unfilled wall frames to completely finished insulated panels including cladding and even windows and glazing can be pre-assembled. [38]
4. DISCUSSION

Because transformable building demands another way of thinking than for traditional building elements and many design choices have a great influence on the transformational capacity, adaptable building concepts have to be integrated as soon as possible in the design process, which was confirmed in an earlier study [21]. The application of the design guidelines influences the ease of deconstruction and therefore influences the eventual consumption of resources and the waste generation of the building too.

Leaflets were developed in order to give information about the design guidelines of ‘Design for Change’. The leaflets are online available and can freely be consulted via the website of OVAM. Figure 16 illustrates one of the leaflets. The information was spread online to reach as many people as possible and to make it easy to adapt the leaflets in the future. However, at the moment the leaflets are only online available in Dutch.
PUBLICATIONS


REFERENCES


