Adaptable skin systems

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Abstract. Most buildings are continuously changing. Renovation, layout modifications, and other physical changes are usually complicated processes associated with losses in materials and assets. The building industry is responsible for a vast amount of the global waste. Therefore a shift towards circular solutions is crucial to minimise this negative environmental impact. This paper is based on the master thesis, A Tale of Layers, completed in spring 2018 at Chalmers University of Technology, and provides further discussion on the results. The thesis developed a set of design strategies for adaptable skin systems, and focused on a design proposal of ‘the connection’ which is a reversible connection system between the structure and the skin of a building. The aim of ‘the connection’ is to increase the building’s adaptability and the circular use of materials. It allows transformations in the skin with minimal effects on the structural system to preserve its quality and value. The design strategies and ‘the connection’ can be applied in different contexts, while the skin systems alternatives presented are specific for the extension of Snäckeback School in Ronneby, Sweden. Separating the different building systems and following standard dimensions and modular systems make buildings easy to repair and adjust according to the changing demands and increase the possibility for materials reuse. However, they can limit the buildings’ shape and form. Creating skins with variable U-values is an additional benefit of separation, allowing the skin to be one factor that contributes to optimising the building energy performance in some climates.

Keywords: adaptability, skin, systems separation, reversible, circular economy, variable U-value.

1. Introduction
Buildings are not permanent or fixed as they seem to be. On the contrary, they are in a continuous state of change driven by the frequently changing demands and preferences of the modern society. Even if the function of the building remains the same, it needs to go through processes of maintenance and renovation at some point.

The adaptability of the building benefits the users by responding to their new needs in a simple manner. It contributes to the continuity of the building’s life of service, and keeps at least the value of the building, if not increasing it. It also minimises the negative impact on the environment through
minimising materials waste and the need for new materials. Adaptability can be defined as “The capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing value through life” [1, p. 3]. However, most of the buildings are not designed with the possibility of change making the physical adaptability of buildings an expensive complex process. “Designers tend to ignore these temporal aspects focusing on an aesthetic fixation and functional performance, freezing out time in pursuit of a static idealized object of perfection” [1, p. 2]. In many cases, buildings can be demolished as they fail to satisfy the new demands, even though some of the buildings’ valuable systems, like the structure, might still be in good shape. The linear approach of consuming the materials results in enormous amounts of wasted materials and discards their value after a single use. The building industry is responsible for the use of up to 40% of the materials produced globally and about 35% of the world’s waste [2]. This rings the alarms to adopt the concept of circular buildings that aims to maximize reusing and recycling materials by focusing on the reversible configuration of the building components and the materials selection criteria. Circular buildings also provide more capacity for change because of their reversible design.

Considering the time factor and understanding the building systems are fundamental aspects for designing adaptable architecture. Brand’s shearing layers diagram describing the building systems and their rate of change provided the dimension of time to the buildings [3]. He argued that the slow changing layers, like the structure, dominate the faster-changing ones, like the skin. The skin is one of the most valuable and essential building systems that has a relatively high rate of change.

2. Methodology
Research for design is the main method used for this study. Topics like buildings adaptability, Systems Separation, Design for Disassembly (DfD), and circular economy were explored to be summarized in the form of design strategies for adaptable design solutions. The design strategies were followed in creating a design proposal of skin systems to Snäckeback School in Ronneby, Sweden.

3. The context: Ronneby Municipality and Snäckeback School
Ronneby municipality, south of Sweden, have adopted the Cradle to Cradle philosophy as a methodology for their future development. One of the main principles that Ronneby focuses on is managing the resources; where the biological materials should be able to go back to nature as nutrition and technical materials can be recycled as raw materials for the industry [4].

Snäckeback School in Ronneby was built in 1913 and has been through several changes since then in the form of expansions and renovations. Starting out with one building, the school is now comprised of a complex of five buildings. Currently, a bigger change is on its way. It includes the deconstruction of some of the buildings, because they are not satisfying the city needs, and adding new extensions. The design proposal is suggesting skin system alternatives for the new extensions aiming to increase the building’s capacity for change, and promote using circular materials, where materials are seen not as a disposable product but valuable assets to be conserved for reusing and recycling.

4. Design background

4.1. System Separation
System Separation strategy was developed by the Office for Real Estate and Public Buildings of the Swiss Canton of Bern to consider the hierarchy of lifespans of the building components, to open the possibilities for future modifications [5]. The strategy categorizes the building components into three levels; Primary systems of long lifespans including the structural system and the facades; Secondary systems of medium lifespans including the services systems and the interior space plan system; Tertiary systems of short lifespans including the furniture. One of the main purposes of the strategy is to allow transformations within the shorter lifespan components without affecting the components of longer lifespans. Figure 1 shows the relation between the building systems and their level of adaptability in most conventional buildings.
Figure 1. Relation between adaptability and building systems

The primary systems hold the higher value of the building, and have a longer life of service but are usually designed as if they will never change making the transformation of these systems expensive and complicated. Primary systems create the boundaries for the physical adaptability of buildings, either as a facilitator of change or as a dead end. Systems Separation brings higher adaptability of the building overall when the systems are not combined in one component and not dependant on each other. Maison Domino designed by Le Corbusier in 1914 evidently separates the structure from the skin (figure 2). This concept can be even implemented with other structural systems like timber or steel structures.

Figure 2. Maison Domino by Le Corbusier. The concrete structural system of slabs and columns gives freedom to the facades to become more flexible for change.

4.2. Facades functions and configuration

Facades perform several functions but mainly they define the architectural appearance of the building and create the climate shell. Generally, the facade can be separated into three layers to protect against different environmental factors (figure 3).

Figure 3. Three layers of the skin providing protection against different environmental factors.

These layers can be of one or a limited number of materials; an external layer protecting against rain, wind and solar irradiation; an intermediate layer providing thermal insulation; and an inner layer separating the interior space from the exterior [6]. Durmisevic showed three design domains of configuration design for transformable buildings; functional, technical, and physical [7]. Knowing the purpose of the configuration as a whole and the properties of the layers such as their function, durability and their physical role in the configuration help the designers plan the disassembly and priorities the access to the desired layers for future modifications.
4.3. Design for Disassembly
“Design for Disassembly is a holistic design approach where the intention is to make any given product easy to disassemble into all its individual components” [2, p. 41]. DfD brings the benefits of physical adaptability and material reclamation for reuse and recycle, hence less waste. DfD focuses on the joints and connections between the different components in a way that facilitates the disassembly without damaging the other components. Durmisevic discussed the relation between the functional integration within the building elements and its impact on the building flexibility. She recommends the separation of functions and allocating them to independent components (figure 4). Accordingly, the transformation of one function will not impact the other functions. Durmisevic presented different connection types and analyzed their level of flexibility. Having an additional fixing device joining the elements gives the advantage of changing without affecting the other elements, and increases the possibility for elements reuse and recycling (figure 5) [7]. The additional fixing device was the inspiration for ‘the connection’ presented in section 5.

![Figure 4. Separation vs. integration of functions.](image)

![Figure 5. Flexible connection by Durmisevic, 2006.](image)

4.4. Waste hierarchy
The ‘circularity ladder’ gives priorities for the use of resources and waste preventions. It is a development of the European commission waste hierarchy (prevent, reuse, recycle, and dispose) connected to the strategies used by the Ellen MacArthur Foundation [8]. In the last two levels, recycle and dispose, the material flow can be divided into two cycles: biological materials and technical materials. The biological materials are meant to integrate back into the biological cycles through composting or fermentation for instance. The technical materials are to be integrated in closed loops of recycling, upcycling, or eventually disposed by incineration or in landfills.

It is important to consider the form of how the materials will be reclaimed; as components to be reused or as materials to be recycled. Generally, reusing building components with minor modifications is determined by the dimensions of the components and the fixing method. Therefore, following the standard or modular dimensions and commonly used fixing methods would facilitate components reuse. Furthermore, the components should be designed in a way that allows their disassembly without damaging the integrity. The materials that will be upcycled or recycled should have reversible connections, i.e. not glued or mixed with other materials hindering the recycling process.

4.5. The design strategies
These design strategies aim to help designers in creating adaptable skin systems, but also can be applied to the different building systems [9]:

- Systems Separation: separate the structure from the skin system. Also separate functions into separate components where possible.
- Oversize the structural elements: to allow for expansions, keep the possibility for future modifications of the element, and earn future economical value of the elements.
- Standardisation and modularity: design to standard dimensions or modules to reduce materials waste and increase reuse possibilities.
Select reusable, recyclable materials: materials that can be integrated into the technical cycles or the biological cycles.

Hierarchy of lifespans: consider material lifespans and rate of change.

Accessible and reversible connections: place connections to be easily accessed and use connections that do not need special tools for disassembly.

Avoid material damage: replacement or modifications of shorter life elements should not affect or damage the elements of greater durability.

Open possibilities: design to create more possibilities to correspond to unexpected future needs.

5. The design proposal - ‘The connection’

5.1. ‘The connection’

‘The connection’ is an element made of timber that acts as a joint between the structure and the skin. This proposal suggests that the slabs would have holes to attach ‘the connection’ mechanically by bolts and nuts. ‘The connection’ extends along the slabs matching the structural modules. Choosing timber as the material for ‘the connection’ is because it is a natural, biodegradable material and has strong structural properties. It is also easy to adjust on site. Vertical mullions attached to ‘the connection’ create the support for the skin and distributed horizontally to a suitable module that can be altered depending on the facade design and the materials used (figure 6). The different skin layers can be filled-in or added-on the mullions. The purpose of ‘the connection’ is to protect the valuable structural element from damage when dismantling the skin that has a higher rate of change by separating the functions to different components.

Figure 6. Diagram showing 'the connection' and its assembly in relation to the structure and the skin.

5.2. The bricks skin- an example using ‘the connection’

This skin system reuses the bricks from the deconstructed school buildings as the exterior layer of the skin (figure 7). Stainless steel supports carry the bricks and are attached to ‘the connection’ for easier disassembly and access to the other skin layers. The bricks are stacked in two different modular patterns; a closed pattern and a perforated pattern. This is because the quantity of the bricks from the deconstructed buildings that can be reused is unknown until the actual deconstruction time.
5.3. ‘The connection’ benefits and limitations

The advantages of this system can be highlighted in two main points; adaptability and preserving the materials value. Unlike buildings that are made of compact walls acting as structure, insulation, and skin, this system allows the transformations of exterior walls or some of its layers without affecting the whole building’s integrity as the structure can still be standing. Therefore, it brings more capacity for physical change for the skin and the building as a whole (figure 8). This system would allow the skin to be transformed as layers or in modules of several layers. This system can preserve the value of the materials by prolonging their life of service as it allows the reuse of the modules with minor or no modifications, especially when separating the layers of the skin by keeping the materials unmixed with other materials. The reuse can be of a single material like exterior cladding, or it can be the reuse of modules of multiple layers as one entity. For instance, a wall module including exterior cladding, insulation and interior finishing can be reused in a different building.

On the other hand, ‘the connection’ could perform as a thermal bridge through the timber to the slab; one suggested solution is to add a layer on the outside of a thin high-performing insulation material. Another alternative would be to change the material of ‘the connection’ to a material with low thermal conductivity but with strong structural properties.

It is beneficial to follow the standard dimensions of material panels to minimise waste of materials during the construction, like using the width of 600 mm, 900 mm and their multiplications. Also adopting commonly used mechanical fixations that don’t require special tools is a key element for easy maintenance or disassembly. When many buildings adopt these recommendations, it will open more possibilities for the materials to be integrated into different cycles not necessarily within buildings that have the same material supplier. The main point is to open as many possibilities for the materials to be integrated into circular systems to prevent their disposal. Achieving such circular solutions requires collaboration among the different stakeholders; architects, engineers, material manufacturers, and entrepreneurs.
Although most of the buildings have simple cubic forms, ‘the connection’ skin system can restrict the design to such forms. However, it brings the benefits of adaptability and circularity. For buildings with complex, unique forms, the principles of ‘the connection’ can still be applicable by separating the structure from the skin and adding a reversible joint in-between. The custom-shaped materials have lower chances of reuse, and the focus should be on allowing recycling or upcycling the materials.

6. Further explorations of skin layers separation

‘The connection’ which depends on the separation of the skin layers can bring further advantages for the building. For instance, the easy access to the thermal insulation layer opens the possibility for the U-value of the skin to alter creating adaptive solutions to optimise the building’s energy performance. “For cold climates and buildings with a high heat load, the optimal U-value varies. When the heat load peaks, there is a need for cooling while heating still is needed cold days and when the activity is low. A low U-value would help to keep the warmth indoors when heating is needed while a high U-value would help to cool the building when the outdoor temperature is lower than the indoor temperature.” [10]. The following two proposals are explorative trials to achieve a variable U-value skin on a macro level by altering the insulation layer itself. They give the opportunity for the skin to be considered as a parameter that can be altered like HVAC systems or shading devices contributing to the indoor thermal comfort. It can be useful as a cooling strategy during summers in Sweden as most of the buildings are not prepared for warm weather.

6.1. Variable U-Value: Two skin systems proposals

In the first proposal, an empty air gap between two polycarbonate panels can be filled by mycelium panels, as the thermal insulation, in the cold season (figure 9). The mycelium has good thermal insulation properties making the U-value of the skin drop from 0.3 (W/m²·K) to 0.1 (W/m²·K).

7. Conclusions

Adaptability is one of the important aspects of sustainable design as it brings benefits whenever the need for physical change emerges, whether on the short-term for maintenance or adjustments, or at the end of service facilitating the disassembly and materials reclamation. System separation, and even separation of functions within the systems, increases the adaptability especially when the rate of
change, the hierarchy of assembly and the components interdependencies are considered during the design phase. Using the extra reversible joint in ‘the connection’ helps to protect the primary valuable structural components from damage caused by changing other short-life components. The separation of the skin layers highlighted the possibility to achieve variable U-value skins by altering the insulation layer, which is a possibility that can be explored furthermore. It can be a strategy to cool down buildings in the warm summer days in a Swedish context. Setting the project’s goals regarding handling the materials at the end of service is important during the design phase as it affects the configurations design. Projects that have customised designs should consider facilitating materials upcycling or recycling. ‘The connection’ and the skin systems proposed are a first step for more collaboration among architects, building engineers, material manufacturers, and entrepreneurs to create circular solutions. Standardisation and modularity facilitate building components reuse, but they could limit the freedom of the design leading into monotonous buildings. This raises the questions: Do buildings that aim to allow the reuse of its components have to be linear and modular? Do these buildings have to sacrifice the different architectural possibilities and stick to repetitive modular facades? And how will buildings that are reusing components from older buildings look?

8. References

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