Adaptability enablers for timber intervention: A literature review and investigation of parametrization potential

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Abstract:

This research addresses the pressing need for adaptable architecture in rapidly urbanizing societies, focusing on the transformation of underutilized urban industrial buildings into adaptable student housing. Recognizing the challenges of modern urbanization, such as increasing single-person households and the resultant demand for individualized dwellings, the study explores adaptive reuse as a sustainable solution. It emphasizes preserving the historical and cultural significance of existing structures while infusing them with new life to meet contemporary and future demands. The methodological approach integrates a thorough literature review on adaptability in architecture, and timber construction, translating constraints into mathematical parameters suitable for informing a parametric model. The study concludes by establishing a comprehensive framework for designers using adaptable architecture principles and timber construction constraints to inform the development of a parametric model. It involves a strategic assessment of design possibilities within these constraints, aiming to balance aesthetic innovation with practical limitations

Keywords: *adaptability, flexibility, transformable architecture, timber, dimensioning, rules of thumb, construction systems, parametric design*

1 Introduction

The world's population has become predominantly urban [UN, 2018], resulting in an increase in single-person households [Eurostat, 2022]. This puts immense pressure on cities to meet the demand for individual dwellings. And as societal dynamics undergo transformative shifts, these changes are also reflected in the way the society views and uses their homes. Meanwhile, rapid urbanization is challenging construction practices to address growing housing needs. This often results in overlooking sustainability and prioritizing the present over the future. As a result, the built environment accounts for a major portion of global CO2 emissions and waste production [Con, , European Commission, 2008] while the designs outlive the societal demand but are not designed to adapt to the changing needs of the users. As such, it is often seen as more feasible to demolish the building rather than transform it.

Simultaneously, many urban industrial buildings remain unused or underutilized. These structures, once on the city outskirts, now lie at the urban core due to expansive urbanization, presenting an opportunity for adaptive reuse. Adaptive reuse not only conserves resources but also upholds cultural and social sustainability, turning these buildings into potential cultural hubs. Several examples in the Netherlands, like Strijp-S in Eindhoven [Strijp-S,] and Amsterdam Noord[NDSM,], illustrate this potential. For cities like Rotterdam, industrial activity played a pivotal role in their development, imbuing them with significant identity value [Nientied, 2018].

The goal of this graduation project is to create a design that anticipates shifts in societal and environmental needs, influencing how the architecture is utilized. Despite the attempts to forecast the future, its uncertainty necessitates designs that allow efficient adaptation to various scenarios. Consequently – the key aspect of the project is to ensure the adaptability of the designed intervention on both macro and micro scales. Student housing is assumed to be the momentary function, however, the designed intervention must cater not only to the present housing needs but also anticipate potential future spatial, structural, and functional changes. This means considering flexibility at the individual user level while also foreseeing significant architectural alterations at a broader level.

As such, this research aims to establish which preliminary considerations should guide the design process and which specific characteristics should the final design incorporate, to achieve maximum adaptability within the given conditions. These conditions include the role and the state of the existing structure, the material limitations and the design goals while at the same leaving space for the freedom of the designer.

The selection of timber as the primary material is driven by sustainability concerns, as well as its suitability for renovation. Timber construction offers several benefits, including lightweight construction ideal for vertical expansion in load-limited structures, versatility allowing for unrestricted design in form, façade, and interiors, and high prefabrication level which ensures quick, quiet construction, minimizing neighbour disturbance[Schuetze, 2018]. Currently, there are rapid advancements in timber engineering, which yield new engineered timber materials and production technologies. However, constructing with this material is governed by specific construction constraints including various critical design aspects such as structural properties of the specific material, dimensions of the elements, connections, and so on. Hence, this research also focuses on identifying independent or interdependent constraints and dimensioning rules for timber construction.

Parametric design

Alongside shifts in societal dynamics and environmental conditions, there are changes in architectural practice. The shift towards digitisation is indubitable. Architectural tools are rapidly being developed and improved, one of the newer additions being the utilization of artificial intelligence in the design process. However, the architectural specialisation as a whole doesn't adapt quickly enough. Some professionals in the architectural field continue to romanticize traditional design approaches, relying on intuitive thinking, drawing, and freehand modelling. The designers and architects often start the process first by thinking about the graphical characterises of the design, making initial decisions on the subjective feeling of aesthetics, spending a lot of time on the form, and geometry or diving directly into the detailing etc. Yet, at its core, architecture is about strategic thinking. It involves research to define the building's purpose and then making decisions to achieve those aims, with the design emerging as a product of this process.

The preference for using traditional tools, or rather, for using digital tools traditionally, occurs despite the vast new computational capabilities available today [Igor Svetel et al., 2018]. Parametricism was defined by Patrick Schumacher in the year 2008 as a style of architecture and approach to designing [Patrik Schumacher, 2008]. The method of parametric design facilitates an adaptable approach wherein the parametric model is created based on certain rules, which can be either conditional or unconditional. Each aspect of geometry is defined not as separate objects but in relation to each other through parameters. The designer decides which parameters can be modified and which ones cannot. By changing the modifiable parameters, the geometry of the design can be altered while still adhering to the unconditional parameters. This allows for changes to the design without compromising its integrity. While the practice has been known for more than 15 years, according to some data, as of 2016, only 3% of the top 50 architectural companies of the world required knowledge of Grasshopper for McNeel Rhinoceros [Black Spectacle, 2014], one of the most common parametric design software. The parametric method enables data-driven design within predefined constraints while optimizing labour and enhancing workflow efficiency. If used wisely, it can streamline creativity and design exploration, given the computational power of the computers is much higher than the one of the human brain. Not only is this approach more practical on its own, but the resulting designs also become more feasible and relevant. Designs rooted in extensive data not only justify specific design choices but also allow for effective modifications if the input data changes. It is essential to recognize that parametrization is not the end result but rather a tool, ensuring designs align with actual conditions as reflected by the input data. It is a tool for the designers to explore multiple project directions and efficiently test and analyze design variants for constraints such as feasibility, efficiency and other performance aspects while allowing the architect to focus on the thinking and decision-making aspects of the process. Another very important benefit of parametric design is its potential to ease the manufacturing of elements. Parametric design tools allow for machine manipulation through computer programming. The details that define the shape of a product, previously set manually for each machine operation, are now embedded in the machine itself. This dynamic information flow from the control software allows for the creation of differently shaped components without incurring any delays in the manufacturing process, eliminating the need for mass production [Buri and Weinand, 2011]. In the context of adaptable timber construction, parametric modelling is pivotal for applying researched rules and guidelines. By establishing core rules and modifiable parameters, the model aids designers in exploring and optimizing designs. Changes in one parameter dynamically adjust others, ensuring structural efficiency and flexibility to adapt to variables like grid patterns or column numbers.

Despite its potential, the use of parametric design in transformation projects, especially in designing adaptable structures, is limited, with few examples like company Respace [Res,] demonstrating its application. Incorporating existing structural constraints and societal and environmental data into parametric models can lead to informed, adaptive designs that respond to changing needs and conditions

Accordingly, the focus of the research can be formulated in the following research question:

Q: How can the design principles of adaptable architecture, in conjunction with the specific constraints of timber construction, inform the development of a parametric model and act as general design guidelines for the adaptive redesign of an industrial building into student housing?

To investigate this multifaceted question, the research is structured into the following sub-questions which will be explored individually:

Q1 Which theoretical approaches and practical principles of transformable and flexible architecture are most effective in guiding the adaptive redesign of industrial buildings for student housing purposes?

Q2 What are the key considerations and constraints associated with timber construction, and how can these be quantitatively expressed and integrated with principles of adaptability to enhance their application in parametric modelling?

2 Method

2.1 Design position

Different design objectives and circumstances necessitate varying degrees of intervention. Working with existing structures inevitably raises the dilemma of balancing preservation with creative liberty. In their book, Plevoets and Clempoet discuss various strategies for adaptive reuse. They explain how different elements of the original building hold historic and architectural significance for the genius loci (spirit of the place). Therefore, different strategies demonstrate various approaches to understanding the poetic relationship between the old and the new. Façadism is a "practice of preserving historic façades and the construction of new buildings behind it" [PLEVOETS and VAN CLEEMPOEL,]. It has been used as a strategy to improve a building's functionality, aesthetics, and urban performance, creating a dichotomy between the exterior and interior. This concept emphasizes not following the traditional idea of the exterior of a building directly reflecting the interior. Façadism is a technique that allows the preservation of a building's historical context while enabling it to serve a new purpose and remain relevant to changing needs. This creates a dialogue between the old and new, resulting in a multi-layered structure that serves various purposes [PLEVOETS and VAN CLEEMPOEL,]. This approach reflects the position of this research as in the context of this project, the focus lies on maximizing the potential of the site and the existing building to respond to the current demand while enabling efficient future transformations.

James Douglas [Douglas, 2006] classifies the range of interventions based on the goal of the adaptation and the severity of the interference into 8 ranges. The graph demonstrating this classification can be found in Appendix 5.1. The severity of intervention in this project lies in the upper grade of this classification, anticipating renovation (upgrading) and remodelling (improving and extending) of the interior space to fit contemporary demands and conditions while allowing the aesthetical value of the facade to carry its cultural identity into the new purpose. While diverse in characteristics, industrial buildings often share spatial and structural features conducive to easy adaptation. These typically include large spans, open spaces, frequent openings in external walls, and a sturdy external structure [Loeff, 2006]. However, they were often constricted to comply with minimal thermal requirements [Douglas, 2006].

It's anticipated that certain elements of the existing building may restrict the new design's possibilities. Consequently, the design anticipates a large degree of intervention, predicting major structural alternations. This may be because the load capacity of the building no longer meets modern safety requirements for the intended new function. Alternatively, the building's capacity may be increased by removing and re-planning the original floors or walls. Therefore, in the process of selecting a building for transformation, considerations of the inside structure will be made. Evaluation will be conducted on which internal elements will support the design and therefore will be kept, and any elements deemed restrictive to the design will be removed. Should the removal of structural elements compromise the building's integrity, the remaining original structure will be fortified in accordance with the researched design strategies to enhance its adaptability further. This approach grants considerable freedom to the designer to optimize the spatial and structural configuration, aligning with the design's predetermined objectives. However, the selection of a building for intervention will prioritize structures without internal load-bearing constraints that may limit this freedom. Considering the chosen façadism strategy, special consideration will be given to the exterior image of the building and its value of preservation. As such, within the Dutch context, the buildings with the status of "Beeldbepalend gebouw"(Image-defining buildings) will be deemed most suitable for this transformation. The Rotterdam municipality defines this status as "buildings that have an important visual value in a neighbourhood or district. But do not qualify for a status as a municipal monument or national monument. [...] The intention is that such buildings remain preserved and recognizable. To this end, these buildings are given a dual cultural history designation in the zoning plan." [Gemeente Rotterdam,]

2.2 Methodology of the research

The primary aim of this project is to repurpose an existing structure into student housing while also ensuring its adaptability for future transformations. This means focusing on both accommodating current housing needs and anticipating future shifts of demands for spatial organization or function.

The research starts with an extensive exploration of the existing literature, exploring the theoretical concepts, categorisations and definitions of adaptability and establishing one definition and focus category for this research. The literature review intends to synthesize the literature for design approaches and characteristics that contribute to the potential of the building to be easily adapted. A comprehensive selection of practical design characteristics is essential for enabling the selected adaptability degrees in the context of this project's objectives.

The construction limitations associated with timber structures necessitate exploring independent or interdependent rules governing timber construction. The second phase of the literature review research focuses on identifying these rules, employing conducting a detailed examination of timber constraints that directly impact selected parameters crucial for developing the parametric model. After that, the synthesis of established rules of thumb for timber structure dimensioning, gathered from diverse sources, is compiled into a comprehensive rulebook informing the parametric model.

The development of the parametric model is the guiding aspiration of this research, enabling a dynamic approach where alterations in design inputs trigger automatic updates across the entire structure. The research on material characteristics for timber construction has led to the identification of constraints. These will be translated into the form of minimums and maximums, and mathematical relations, that would act as the basis of the parametric script. As these parameters have a direct impact on the structural integrity of the building, they are considered unconditional. At the same time, the script will allow designers to modify conditional parameters, such as ceiling height, span, or element dimensions, which are therefore the conditional parameters. Additionally, the tool should incorporate environmental conditions, optimizing the design to the selected environment.

The script's ultimate aim is to facilitate a more efficient design process by allowing designers to adjust the geometry of the design in response to specific parameter changes, defined by designer goals, environmental conditions, regulations etc. The unconditional parameters ensure the design complies with the identified set of design principles and a range of parameters that create the underlying framework of the parametric script. This script will function as a tool for designers to experiment with different structural configurations, thus streamlining the design process's efficiency.

3 Results

3.1 System - Adaptability

The need for adaptability in the built environment arises from its current unsustainable trajectory and the evolving demands of society. Traditional static building designs are becoming obsolete in the face of changing user needs and environmental conditions. This necessitates buildings capable of adapting to an array of fluctuating factors, particularly the unpredictability of the future.

One of the sub-questions that the research aims to answer is the following:

Q1: Which theoretical approaches and practical principles of transformable and flexible architecture are most effective in guiding the adaptive redesign of industrial buildings for student housing purposes?

This chapter presents a literature review of various sources exploring adaptability. Firstly, the chapter outlines the different definitions of adaptability and classifications encountered throughout the sources. Then, the term adaptability is defined in the context of this research, and the specific classes of adaptability that this paper will focus on are identified.

Subsequently, the chapter summarises a comprehensive study and methodical assessment of the system characteristics, evaluating their relevance to the research objective. The discussed system characteristics were chosen based on their alignment with the definition of adaptability stated in this research paper and the design position. The selected principles are collected into clusters and re-categorising into Design characteristics (informing physical properties and the geometry) and Design tactics (informing the process and other intangible aspects of the design)

3.1.1 Adaptable and Flexible architecture

Academic research across various disciplines has explored adaptable architecture, attempting to define the theory of adaptable architecture and propose solutions to shift design practices towards creating flexible and transformable buildings. Nevertheless, there remains a lack of a clear, consistent definition of "Adaptability" in this context. Definitions vary based on context and application level, but a common thread is the concept of change, encompassing alterations in use, physical layout, and size. The motives behind creating adaptable buildings often include avoiding obsolescence and addressing changing operational conditions and external factors.

There's also confusion between "Adaptability" and "Flexibility." Some sources view adaptability as encompassing various types of changes, with flexibility being a sub-category. [Douglas, 2006] Others differentiate them based on the nature of the changes – flexibility involves physical alterations to the building, while adaptability focuses on non-physical changes [Till and Schneider, 2016]. Appendix 5.2 provides an overview of the definitions and classifications of the sources used in this research.

The book "Adaptable architecture: theory and practice" by [Schmidt and Austin, 2016] is notable for providing a comprehensive classification of adaptability, dividing it into six types: Adjustable, Versatile, Refitable, Convertible, Scalable, and Movable. Each type addresses different aspects of change, from user needs to environmental adjustments (see Appendix 5.3).

In this research, adaptability is defined as the potential of a building for physical modifications, spatial reconfiguration, functional repurposing, structural expansion, and sustainable disassembly. Focusing on an industrial building intervention, the research aims to design a solution that accommodates current needs while allowing for future changes. This includes small-scale spatial reconfigurations to macro-scale functional transformations and anticipates possible expansions. In line with Stewart Brand's assertion that "All buildings are predictions. All predictions are wrong," [Brand, 1994] this research also explores Design for Disassembly, preparing for the possibility that the most efficient adaptation might be complete removal and replacement. Consequently, the principles of versatility (change of spatial layout), convertibility (change of use), and scalability (change of size) are central to the intervention design. Users play an important role in the way the space is utilised. Therefore the design should enable adaptability on the user level as well. Given that it is expected that different demographic groups will occupy the plot, the housing design as well as the public and semi-public areas should have future elements that enable easy modifications to fulfil the user needs. This will not only enhance the adaptability of the space but also enhance user experience as it will allow them to fit the space to their preference. As such the goal is to create a design that can evolve over time through architectural foresight, on a larger structure scale as well as a smaller user scale. The aim is to ensure that the transformed building can efficiently adapt to future conditions and needs, enabled by a versatile and adaptable design that prioritizes longevity and relevance in a rapidly changing demographic and urban context.

3.1.2 System Characteristics

This section presents summarised System characteristics which include design characteristics and design tactics. The elaborated version can be found in Appendix 5.4 and the original indexing can be found under Appendix 5.5.

Design Characteristics

Layers Designing in layers is stated in multiple sources as a fundamental principle that facilitates the adaptability of the building. This concept acknowledges that various layers of a building have differing lifespans and thus necessitate separation to facilitate timely replacement due to wear and tear or evolving demands. Traditional modern construction often interconnects these layers, leading to challenges where altering one layer may impact or even necessitate the destruction of others. The stratification of a building's layers, as per the widely cited framework by Stuart Brand, categorizes layers into Site (∞); Structure (greater than 100 years); Skin (30-60 years); Services (dependent on maintenance needs); Space-plan (5-30 years); and Stuff (less than 10 years). The design must ensure accessible components, like via dropped ceilings or raised floors, for easy replacement of short-lived elements. This separation and accessibility are crucial for adaptable architecture, allowing independent alteration without affecting the building's other layers. Combining multiple functionalities into a single component further complicates future modifications due to the creation of dependencies [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016].

Loose-fit The load-bearing construction (the longest lifespan layer) is central to a building's adaptability. Its design focuses on a flexible floor plan, essential for future modifications. This is achieved through a generic structural frame, separate from infill and walls, allowing versatile space utilization. Larger spans in this frame enhance adaptability potential. A crucial element is non-loadbearing internal walls, designed to be easily removed or reconfigured without affecting the building's structural integrity or its building physics aspects. This approach allows for easier internal reorganization and the interchangeability of the floor plan [Schmidt and Austin, 2016, Till and Schneider, 2016, Ross et al., 2016].

Simplicity and Legibility The simplicity of construction enables clear and easy reconfiguration. Distinguishing between load-bearing and non-load-bearing elements is essential to avoid adaptation challenges. While layered design offers some clarity, complexity can arise, particularly with components requiring specific manufacturers. Exposed structures, eliminating false ceilings and concealed services, enhance separability, increase space, and improve functionality. Using standardized, interchangeable components like columns and beams simplifies maintenance, and increases reusability. Modular coordination, employing planning grids aligning with structural grid, for furniture and partitions, streamlines standard room layouts and simplifies space subdivision and extension. This aligns with structural grids, fostering versatile design. Simplifying plans into linear or rectangular shapes with clear, straight lines ensures a coherent, adaptable structure, facilitating easier modifications and maintaining functionality over time [Schmidt and Austin, 2016, Till and Schneider, 2016, Ross et al., 2016].

Spatial planning This research aims for adaptability in housing design, enabling unit dwellings to join or divide. Key considerations include access, security, services and spatial arrangement. Effective expansion relies on a well-planned spatial, structural and circulation layout Rationalizing room sizes enhances interchangeability, a factor that is especially important in large-scale projects. Simultaneously, providing varied spatial sizes caters to a range of activities. Striking a balance between standardized and diverse room types often complements open-plan spaces. Grouping spatial zones by function further contributes creation of adaptable spaces. This includes segregating fixed areas like vertical circulation or wet spaces in residential developments. Utilizing standard locations for hidden service elements exemplifies simplicity in design. Standardized fittings, fixtures, and modular storage placed in standardized grid locations further reinforce this concept of adaptability and efficient space utilization [Schmidt and Austin, 2016, Till and Schneider, 2016, Ross et al., 2016].

Overdesign capacity Overcapacity design in structures, like anticipating load increases for future internal and external expansion, enhances building adaptability and future safety compliance. Increased floor-to-ceiling heights facilitate false ceilings (allowing separate service runs), better cooling, and natural light. Double-height spaces allow internal growth, like adding a mezzanine. Overdesign of internal and external circulation spaces can transform from passageways to social or functional areas. Wider external areas can become informal sitting spaces, while larger internal spaces can serve as storage or small rooms [Schmidt and Austin, 2016, Till and Schneider, 2016, Ross et al., 2016].

Design for Disassembly Design for Disassembly (DfD) is key in adaptable building design. It focuses on easy dismantling and reuse of elements. DfD demands specific structural forms for easy disassembly and longevity. The following section repeats some of the adaptability characteristics mentioned above but now relates them to the DfD philosophy, emphasizing its relevance and importance. Correlating with the principle of design in layers, it is important to avoid composite materials and inseparable elements assembled from different materials, as those are harder to separate and later recycle. Separating the structure from the cladding increases adaptability and aids in distinguishing between non-structural and structural deconstruction aspects. Connections should not be covered by secondary finishes as it makes it difficult to later find these connections when disassembling. Similar to the separation of materials, the systems (Mechanical, Electrical and Plumbing) should also not be tangled into host assemblies. A grid-like post and beam layout (loadbearing columns instead of walls) is central to DfD, simplifying the design and concentrating the structure at fewer points or planes. This approach is particularly effective in buildings with large open spans and external load-bearing elements, as non-loadbearing partitions are easier to remove and reconfigure. The visual clarity offered by a post and beam framework, characterized by visible joints and minimal dividing elements, indicates the potential for straightforward disassembly, which is essential for adaptability. A critical strategy in DfD is to minimize the variety of components, thereby increasing the quantities of similar recoverable components. The design should take advantage of using standard and limited palettes of structural elements, connectors and fasteners to reduce the number of needed tools and simplify the switch between them. The design should also prioritise standardised components. Finally, the accent in this approach often lies in creating easily reversible, mechanical connections which often suggest utilizing bolted, screwed, and nailed connections. However, these joints and connections should be designed to withstand repeated assembly and disassembly. To minimize the need for destructive disassembly methods, elements should be designed with adequate allowances. [Schmidt and Austin, 2016, Till and Schneider, 2016, Ross et al., 2016, Brad Guy et al., 2008]

Design Tactics

Design for durability In construction, selecting sustainable, durable materials is vital for adaptability. Resilient materials simplify construction and align with local practices, ensuring availability for future modifications and upholding sustainable building methods. [Schmidt and Austin, 2016]

Prefabrication Off-site prefabrication is key to sustainable construction, enhancing efficiency and precision. This method supports clean, precise building, aligning with modern sustainable and adaptable construction practices. The use of standardised prefabricated elements allows easier reuse, while prefabrication of wooden elements offsite ensures quick construction [Schmidt and Austin, 2016, Brad Guy et al., 2008]. At the same time, when working with large timber structural systems in existing buildings, which encompasses various constraints, prefabrication can offer a great degree of customization while maintaining precision which enables the creation of tailored innovative solutions. This can be executed on the macro scale of structure, enabling a higher degree of precision in dimensioning of elements, but also on the level of details, enabling more sophisticated connections. It is important to note that prefabrication might become limiting when the aim is to enable alternations. Therefore, a holistic approach, including careful planning and system development, is necessary to ensure compatibility with the existing structure and other prefabricated elements. In this context, modular coordination plays an important role. Designing components with standardized dimensions and interfaces, enhances interoperability between modules, simplifying the process of incorporating alterations into the existing structure by enabling the replacement or reconfiguration of specific modules or groups of modules rather than the entire system.

Building function Maximizing building use is key for functionality and financial success, focusing on extending its daily, weekly, and yearly usage. This enables serving diverse groups at different times, boosting utility and relevance. However, mixed tenures bring challenges, like differing operational hours, and requiring separate access and services for various occupants. Design should feature isolatable spaces for flexible and efficient usage, catering to varied user needs [Schmidt and Austin, 2016].

Information The adaptation of a building begins with assessing the existing structure, which can be challenging without clear information. Detailed documentation, including floorplans, reports, and maintenance records, is crucial. BIM (Building Information Modeling) practices enhance this documentation process. [Schmidt and Austin, 2016, Ross et al., 2016] Material passports, as defined by Van Capelleveen et al. [Van Capelleveen et al., 2023], are digital tools providing comprehensive product information, covering the entire life cycle and focusing on sustainability, value, and end-of-life uses. For designs intended for disassembly, labelling connections and a deconstruction plan are essential for successful implementation.[Brad Guy et al., 2008]

The section discussed various design characteristics that increase the potential of the building to be adaptable. The characteristics have been studied and their effectiveness has been evaluated by several scholars through various methods. In one particular study, the author compiled a list of "Adaptability enablers" and then invited 20 experienced design and construction professionals to participate in a survey which ranked the enablers based on their effectiveness. The experts consulted in the survey identified the most impactful design facilitators as precise building information (Information), additional capacity in building systems (Overdesign capacity), segregating building systems based on their replacement frequency (Layers), and interior spaces with easily removable partitions (Loose-fit). [Ross et al., 2016]

3.1.3 Sub-conclusion

The research underscores the increasing necessity for adaptable architecture in response to the evolving demands and unsustainable trajectory of the built environment. Amidst the lack of a uniform definition, adaptability primarily involves change in use, layout, and size, addressing obsolescence and varying needs. The study adopts a multifaceted approach, integrating principles like versatility, convertibility, and scalability, particularly focusing on industrial buildings. The researched design principles address adaptability on various scales. The macro-scale adaptability involves design strategies that affect the entire building structure, focusing on long-term adaptability, structural integrity, and the ability to accommodate significant changes in use or capacity. These include the loose-fit load-bearing structure, overdesign, simplicity of construction, durability and multi-functionality of the design. Parallelly, micro-scale refers to design strategies that enable adaptability within individual spaces or on the level of details, allowing for customization or reconfiguration, as well as considering deconstruction of the structure at the end of its lifetime. These include disassembly considerations such as the separation of components, reconfiguration of floorplan by means of avoiding load-bearing internal partitions and component accessibility, allowing easier maintenance. As a result, the researched tactics ensure the design is adaptable for future environmental and societal changes, efficient, and sustainably deconstructible.

3.2 Material - Timber

Construction using timber offers various benefits such as renewability, low environmental impact, and climate change mitigation. The planning stage involves critical decisions about material, structural and connection characteristics. The following chapter summarises key specifics of individual Engineered Wood Products (EWPs), outlines dimensioning rules for each and compares the materials to each other. Subsequently, the chapter outlines some of the structural systems utilised in contemporary timber construction, summarises the possibilities and constraints and synthesizes them into numerical rules. This will guide the design phase, helping to select suitable construction systems and materials based on the principles of adaptable design and subsequently translating the rules into the parametric script. Ultimately, the section aims to answer the second sub-question:

Q2. What are the key considerations and constraints associated with timber construction, and how can these be quantitatively expressed and integrated with principles of adaptability to enhance their application in parametric modelling?

3.2.1 Material Characteristics

The following section summarises the key characteristics and dimensional limitations of the most commonly used EWPs.

Glued laminated timber Glulam, or Glued Laminated Timber (GLT), made from performance-selected wood laminations bonded with durable adhesives, aligns its fibres axially, mirroring sawn wood's shrinkage and expansion. This enables customized shapes like straight, curved, arched, or tapered elements, often used as linear elements such as beams and columns. Stronger than solid timber, glulam provides superior structural strength, and design flexibility, and can support large spans. Its fire resistance enhances building safety. Offers aesthetic appeal, especially in exposed beams and arches. Glulam is suitable for both interior and exterior applications. [Des, b, ThinkWood, 2022, Waugh Thistleton Architects, 2023, Cro,]

Cross-laminated timber Cross-laminated timber (CLT) is made by bonding perpendicular sawn timber layers, enhancing dimensional stability and reducing expansion or shrinkage. Used in floors, walls, roofs, and structures like balconies and staircases, CLT withstands high forces, making it ideal for multi-story buildings. As a load-bearing material, it's particularly suited for panel elements. CLT's benefits include strength, reduced assembly time, fire resistance, sound absorption, and energy efficiency. Its aesthetic appeal and lighter weight compared to concrete enhance its usability. However, its resistance properties make it less suitable for the exterior and are more often used in honeycomb structures as load-bearing internal walls. [Des, b, ThinkWood, 2022, Waugh Thistleton Architects, 2023, Cro,].

Laminated Veneer Lumber Laminated Veneer Lumber (LVL) is produced by transforming logs into thin wood layers known as veneers, measuring between 2 to 4 mm in thickness. The logs undergo a debarking and steaming process before being rotary peeled. Laminated Veneer Lumber (LVL) is created by bonding these veneer sheets together to craft robust structural panels. In standard LVL production, all layers maintain the same fibre direction, usually aligning with the long dimension of the final product. Following the glueing and curing process, the thick panels are cut into board dimensions. This method of bonding veneer sheets enhances structural reliability and minimizes variability by eliminating defects and evenly distributing any remaining flaws, similar to glulam manufacturing. This allows columns and beams to be smaller, allowing more variation in design. LVL is the strongest timber material and is 2x stronger than steel in proportion to its weight. Typically more functional than aesthetic, LVL is not usually chosen for its visual appeal but for its structural capabilities.[Des, b, ThinkWood, 2022]

Glulam

- Beam Width: 60-280mm [Mayr Melnhof Holz, 2022]
- Beam Height: 100-2200mm [Mayr Melnhof Holz, 2022]
- Beam Length: 4000-56300mm [Mayr Melnhof Holz, 2022]
- Stock Beam Lengths: 12000 mm, 13500 mm, 16000 mm and 18000 mm; Stock beam crosssections available in the Appendix, Figure 4 [Mayr Melnhof Holz, 2022]

CLT

- Width: $\leq 4000mm$ [De Groot, 2018]
- Thickness: $36 - 280mm$ [De Groot, 2018]
- Length: $\leq 18000mm$[De Groot, 2018]
- External Walls Thickness: $500mm$ [INBO, 2021]
- Load-bearing Walls Thickness: $350mm$ [INBO, 2021]
- House Separating Floors Thickness: $450mm$ [INBO, 2021]
- Floor Spans: Max $6000mm$, Ideal $5400mm$ [INBO, 2021]
- Minimum floor height: $3050mm$ [INBO, 2021]

LVL:

- Hardwood: Max Length 18000mm; Width 300mm, Height 600mm (beams); 1360mm (panels) [De Groot, 2018]
- Softwood: Max Length 24500mm; Width 75mm, Height 600mm(beams); 2400mm (panels) [De Groot, 2018]
- Stock beam length: available in the , Figure 5 [Finnish Woodworking Industries Federation, 2019])

3.2.2 Structural Characteristics

Different timber components can be assembled to form diverse structural systems which differ in aspects such as suitability for the building's purpose, height of the building, and layout, coupled with construction limitations like load-bearing capacity, site conditions, time, cost, transportation, and the preferred level of prefabrication. The following section presents the most commonly used systems:

Lightweight Timber Frame Lightweight Timber Frame construction primarily consists of floor panels, and external and internal walls, available in open (only load-bearing) or closed (premanufactured with insulation and finishing) panels. Its popularity stems from high prefabrication and standardization levels. The frame, typically constructed with nailed studs and rails made from spruce, pine, or fir, is enclosed by OSB or plywood panels. Key considerations include a minimal panel height of 2400mm and joists spaced 400 mm-600 mm apart, creating a specific grid. The prefabrication of frame elements and panels, particularly closed panels, significantly shortens construction times and eases on-site handling. This method suits various low-rise buildings, offering customization flexibility. Larger panels can be demounted and reused, enhancing recyclability. However, closed panels' integrated linings and finishes limit their recyclability. This construction method thus balances efficiency, flexibility, and sustainability in timber construction. [Waugh Thistleton Architects, 2023]

3d Modular system The 3D or Volumetric modular system involves assembling operational modules, prefabricated with integrated services and finishes, using timber products like CLT, GLT, or LVL and sometimes hybrid materials. Design considerations include on-site assembly methods, acoustics, air-tightness, and moisture control.

Suitable for large-scale, repetitive projects, this method restricts layout flexibility due to its fixed spatial configuration. Module dimensions are transport-dependent, adhering to the EU's maximum authorised dimensions of HDVs used in national and international commercial transport, with typical dimensions being 13600mm long, 2600mm wide, and 4000mm high [199, 1993]. Modules can be fully prefabricated, requiring minimal on-site work, yet transportation and equipment considerations are crucial. While module configuration offers some versatility, their volumetric nature limits post-assembly adaptability. Though theoretically demountable, practical reuse requires design foresight regarding sequencing and connections. This system efficiently streamlines construction but poses challenges in flexibility and transportation efficiency. [Waugh Thistleton Architects, 2023]

2D Panelised system The 2D Panelised system, utilizing prefabricated CLT panels, creates a honeycomb structure for vertical and lateral load transfer, suitable for both floors and load-bearing walls. Effective for low to mid-rise buildings, this system becomes structurally efficient for buildings over four storeys. CLT panels may be thinner on higher levels to optimize material use and reduce foundational loads. The system's aesthetic allows for exposed finishes, aligning with the Soft principles of design. Its lightweight nature also fits well with existing building expansions. Key considerations include CLT panel dimensions (width up to 3000mm, length up to 16000mm, thickness up to 300mm [INBO, 2021] [Des, b]), prefabrication for precision, on-site erection efficiency, transportation ease, and recycling potential. However, the honeycomb structure's load-bearing walls limit interior layout flexibility. The system's demountability allows for the reuse or recycling of panels, enhancing sustainability [Waugh Thistleton Architects, 2023].

1D Posts & Beams system The post and beam system, utilizing GLM and LVL for beams and columns and CLT for floor slabs, forms a flexible load-bearing structure ideal for reconfiguration. Its efficient grid, typically 6x6 meters, maximizes space while larger spans require deeper beams, influencing floor heights. Columns are designed for up to three stories, considering transportation and installation limits. Prefabrication of structural elements streamlines on-site assembly, with compact stacking enabling efficient transport. The system's open spans, devoid of internal load-bearing walls, offer significant layout adaptability. Additionally, the design allows for the demountability of structural components, enhancing reusability and recycling potential. This method effectively combines material efficiency, rapid construction, and adaptability, making it suitable for diverse architectural applications [Waugh Thistleton Architects, 2023].

3.2.3 Dimensioning rules of thumb

The following section summarises the rules for dimensioning the elements that can inform the parametric model.

Mathematical relationships derived from [De Groot, 2018, Finnish Woodworking Industries Federation, 2019]

Beams

- **Floor Beam on Two Supports:**
  - Height of beam: $H = \frac{L}{15}$
  - Maximum span: $L_{\text{max}} = 30000\,\text{mm}$
- **Floor Beam on 3+ Supports:**
  - Height of beam: $H = \frac{L_1+L_2}{15}$
  - Maximum combined span: $L_{\text{max}} = 50000\,\text{mm}$
- **Roof Beam on Two Supports:**
  - Height of beam: $H = \frac{L}{19}$
  - Maximum span: $L_{\text{max}} = 40000\,\text{mm}$
- **Roof Beam on 3+ Supports:**
  - Height of beam: $H = \frac{L_1+L_2}{42}$
  - Maximum combined span: $L_{\text{max}} = 70000\,\text{mm}$
- **Width of Beams:** $W = \frac{H}{8}$

Columns

- Height of column: $h = \frac{L}{20}$ (L = span)
- Crosssection of column: $d = \frac{h}{15}$

Curved LVL elements

- Bending in the grain direction: Radius of curvature $R \geq 450\times$ Panel Thickness
- Bending in the grain direction: Radius of curvature $R \geq 350\times$ Panel Thickness

3.2.4 Connection characteristics

The adaptability principles discussed above highlight the significance of separating different elements to evaluate the adaptability of construction and its potential for sustainable deconstruction rather than demolition. In order to ensure the separation of elements, the assembly process needs to be carefully thought through, with connections playing a crucial role in enabling separability and reversibility. The connections used in standard timber construction can be divided into 3 types: traditional carpentry joints, chemical (glued) connections and mechanical connections [Des, a].

Carpentry joints have been used in built environments for centuries. Traditionally, these are realised by cutting out wood from the members and fitting them together in a specific manner [Des, a]. While the CNC technology has allowed for precise large-scale carpentry timber construction, these connections face challenges in terms of reinforcement, maintenance, and replacement due to low stiffness and strength perpendicular to the grain. While a wide range of carpentry joints are theoretically reversible, their rigidity, flexibility, and robustness often fall short of modern timber construction's functional and durability standards. Moreover, their reversibility is compromised by changes in dimensions over time and fluctuations in moisture levels. [Ottenhaus et al., 2023]

Chemically bonded connections (or glued connections), characterized by their stiffness, typically require less timber and offer a more aesthetically pleasing appearance compared to other connection types. These connections utilize adhesives, resins, or glues to bond timber components under specific conditions, creating a robust bond with enhanced fire and corrosion resistance. However, they tend to exhibit brittle behaviour and can not be easily reversed.

Mechanical connections can be further divided into two main types: bearing-type connections: (Beams resting on the upper surface of other structural elements, fitting into notches and secured with simple fasteners) and dowel-type connections (beams are attached using screws, bolts or other dowel-type fasteners or specifically made steel collars, connectors, knife plates, etc.) [Fonseca et al., 2022] Connections that rely on bearing typically provide a much higher capacity than those using dowel-type fasteners and tend to require less labour and materials [WoodWorks, 2021]. Dowels, made from wood, steel, or other materials, are essentially circular rods that distribute loads between connected elements through a mix of bending and shear forces in the dowel itself, and shear and bearing forces within the wood. Lateral loads are conveyed through bearing stresses between the fastener and the elements it connects, while axial forces are transmitted through friction or bearing to the joined materials. [Fonseca et al., 2022] Bolted connections or threaded rod connections are in theory fully reversible as these elements are inserted into pre-drilled oversized holes. These can be considered as steel connectors. However, other types of dowels, such as the modern self-tapping screws are typically designed for single-use installation due to friction and fusion between the screw thread and timber, making disassembly difficult. Re-installation of screws in the same hole can be challenging but can be overcome by using larger diameter screws or staggering the screws. Traditional coach screws installed in pre-drilled, under-sized holes may be more advantageous for dis- and reassembly.[Ottenhaus et al., 2023]

Metal connector plates represent a specific category of dowel-type fasteners, which utilize flat elements and custom proprietary connectors. These combine both lateral load transmission typical of dowels and the superior strength qualities of metal plates. On the other hand, bearing-type fasteners, such as split ring connectors and shear plates, are specialized for transmitting lateral loads by bearing against the materials to which they are connected. Hanger-type connections, which blend the features of both dowel and bearing-type fasteners, typically support one structural member attached to another through a combination of dowel and bearing mechanisms. [Fonseca et al., 2022]

To assess the potential for reversibility of connections, it's important to evaluate the degree of interlocking among the components, as it affects the separability of the elements. The connections can be stratified as follows:

Infilled or Filled connections When the elements are chemically bonded by filling with another material (glue, resin or another adhesive) or welded together, their separation and disassembly are virtually impossible without heavy destruction methods [Morgan and Stevenson, 2005, Durmisevic Elma, 2006]. These are the above-mentioned glued timber connections or chemically bonded connections.

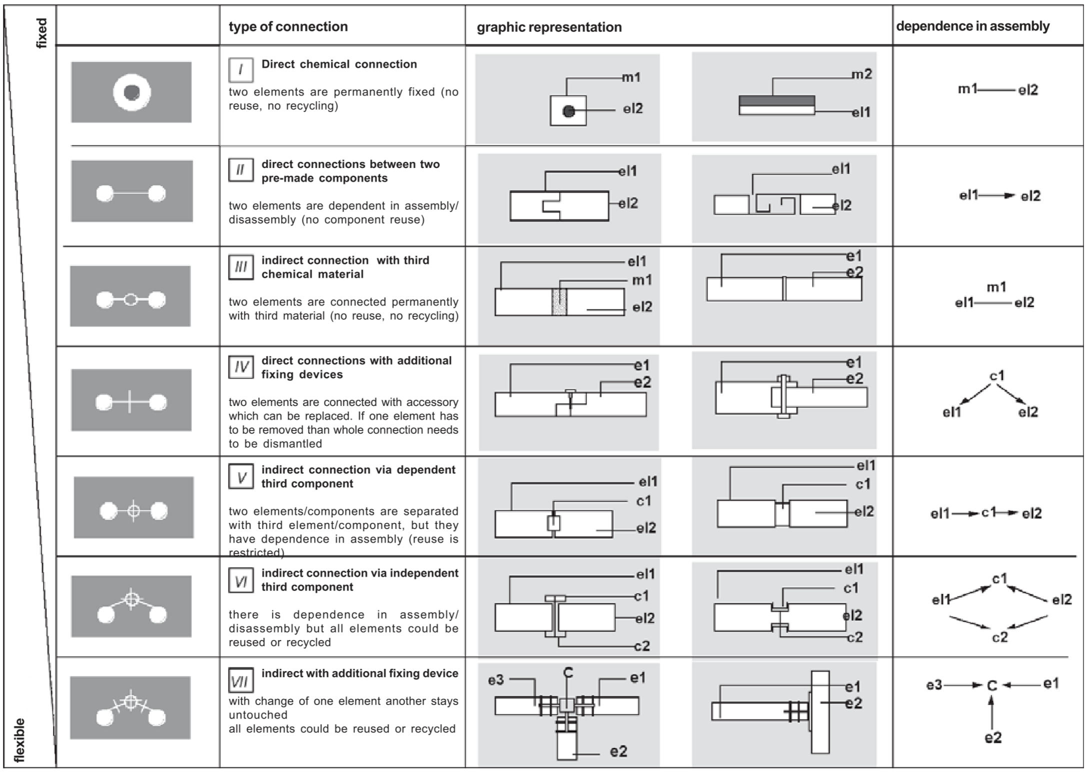
Direct or Integral connections The geometry of component edges forms a complete connection. The elements can interlock or overlap each other, making the disassembly and separation more difficult as it is influenced by the materials used, assembly sequence and component hierarchy [Morgan and Stevenson, 2005, Durmisevic Elma, 2006]. These are the traditional carpentry joints and the bearing timber connections, as well as simple dowel connections

Indirect or Accessory connections These connections utilise extra parts (accessories) that act as connectors between the connected elements to establish a bond between components. Internal accessory connections involve a separate piece that joins the components from within, offering the benefit of matching edge shapes with the components but presenting challenges in dismantling due to the order of assembly. External accessory connections, on the other hand, facilitate easier disassembly and reuse by creating a connection that does not affect the geometry of the elements. [Morgan and Stevenson, 2005, Durmisevic Elma, 2006]. The mechanical type connections which utilize steel elements and proprietary connectors can be classified as accessory connections if they have the above-mentioned properties.

It is important to note that to enable a high degree of adaptability, the components should be both independent and exchangeable. To achieve the highest degree of separability and reuse, the connection should be designed with the aim of maintaining the structural integrity and appearance of the construction elements that are joined, especially during disassembly. Therefore the use of notches, cuts, and holes should be minimized. Friction jointing (utilizing an accessory) stands out as the least intrusive method of joining, making it highly preferable for structural components intended for reuse. Examples of friction joints include timber-on-timber sleeve joints, clamps, and pre-formed sockets designed for inserting elements [Morgan and Stevenson, 2005].

The flexibility degree of the connections has been classified in Figure 1 by Elma Durmisevic. The figure not

Figure 1: ”Seven principles of connections ranged from fixed to flexible connections” [Durmisevic Elma, 2006]



only illustrates the flexibility and classification of the connection but also the assembly dependence and sequence. This has a direct influence on the separation and reuse potential of the elements after deconstruction. From the figure, it is apparent that to achieve the highest degree of adaptability, connections should be indirect with an external independent fixing device (VI), preferably with an independent assembly sequence (VII). This would allow all connected elements to be reused or recycled, potentially even exchanging specific elements while leaving the remaining elements untouched.

3.2.5 Sub-conclusion

This section elaborated on the most common EWPs and structural systems as well as outlined constraints of timber construction that can be translated into a parametric model. From the design point of view, it seems that glulam is the most suitable material for the design goals. Glulam is a lightweight, structurally resistant material, capable of providing large open spans. Unlike CLT, which is usually utilised in panels and is more often used for internal load-bearing structural walls, glulam is often used for liner post and beam structures, inside and outside. It comes in a variety of straight and curved elements offering more architectural possibilities while its aesthetical quality does not require to be covered by finishes and as such the structure can be left exposed.

When compared to each other, different systems offer various advantages and disadvantages. However, the most suitable construction system for the purpose of this research is revealed to be the 1D Post & Beam System. as it closely aligns with the project goals of transforming an existing structure into an adaptable housing. Given that this research emphasizes adaptability, post and beam systems reflect multiple design characteristics discussed earlier. These include large open spans and a lack of internal load-bearing walls. This allows reconfiguration of the layout and accommodates future modifications and changes in function. The system is designed to be lightweight, economically feasible, and support efficient timber usage through the use of structurally efficient materials. The construction specifics allow for the elements to be prefabricated, efficiently assembled and then demounted and recycled which is pertinent when considering the sustainability and adaptability goals of the project. The identified Rules of Thumb offer precise mathematical relationships expressing rules for the dimensioning of an element in relation to each other. As such, the numerical nature makes it possible to translate these as non-conditional parameters in the parametric model.

Finally, connections play a crucial role in enabling or limiting the adaptability and sustainable deconstruction of the structure. As mentioned in the system characteristics chapter, it is important to ensure the design is assembled from separable elements. When designing connections for easy disassembly the aim should be to avoid compromising the quality of all involved elements during deconstruction. Therefore, it is important to follow two main principles: The connections should be bonded using dry-joining methods (such as bolts and dowels and not chemical bonding) as this offers a higher degree of reversibility. Nevertheless, the mechanical connections, though more adaptable, still require careful consideration to ensure they can be easily undone when changes are necessary. As such, they should be designed with minimum interlocking and interdependence of components, utilizing extra connectors that allow independent disassembly.

4 Conclusion

This research used subquestions to thoroughly explore the main research question:

Q: How can the design principles of adaptable architecture, in conjunction with the specific constraints of timber construction, inform the development of a parametric model and act as general design guidelines for the adaptive redesign of an industrial building into student housing?

The study highlighted adaptable architecture's necessity to respond to evolving societal needs and environmental concerns. By integrating principles such as versatility, convertibility, and scalability, the research focused on specific system characteristics that enable adaptability. Design strategies and tactics including Design in layers, loose-fit load-bearing structures, and Design for Disassembly (DfD) emerged as pivotal. Glulam, identified as an ideal material, supports large spans and offers architectural flexibility. The post and beam system, congruent with project goals, enables layout reconfigurability and aligns with sustainable material usage.

The research further identified essential constraints in timber construction—material properties, structural systems, and dimensioning rules—and translated them into mathematical principles for a parametric model. The model can integrate these constraints as unconditional parameters, allowing designers to efficiently create and test designs, translating the shapes of the design into buildable and therefore maintaining control of the design process. Additionally, the adaptability design characteristics advocating for standardized elements and a limited component range can be efficiently managed through a parametric design library, optimizing element selection. The exploration of the specifics of the connections yielded that mechanical connections are to be prioritised, as opposed to permanent chemical connections, and the aim should be to keep the elements as minimally interlocked as possible.

It is important to highlight that some of the researched characteristics are contradicting. For instance, the recommendation to use suspended ceilings for accessible services conflicts with the goal of creating exposed, straightforward structures. The standardisation of room sizes might benefit the interchangeability of space use, however, offering more variability of size enhances the suitability of space for a wider range of activities. This emphasises the complexity of the architectural design process that involves navigating various constraints and contradictions. It is important to thoroughly evaluate the context of each building project, taking into consideration factors such as its intended function, applicable regulations, and local climate conditions. To ensure the longevity and adaptability of the design, it is essential to assess potential future scenarios and make informed decisions based on that evaluation.

Additionally, while the research successfully addressed numerical constraints, a significant portion of adaptability constraints is qualitative. Future research is needed to convert these qualitative characteristics into quantifiable parameters for the parametric model, encompassing a broader range of design considerations. This will further bridge the gap between theoretical flexibility and practical application in architectural design, and enhance architects' ability to design adaptable structures using modern digital tools.

In conclusion, this study establishes an essential framework integrating adaptable architecture principles with timber construction constraints for the architectural transformation of an industrial building into student housing. The application of this framework is critical in guiding the design process. It involves a strategic assessment of design possibilities within these constraints, aiming to balance aesthetic innovation with practical limitations. The objective is to achieve distinctive, sustainable architectural solutions that push the boundaries of design while adhering to the established constraints, ensuring both uniqueness and feasibility in the project's outcome.

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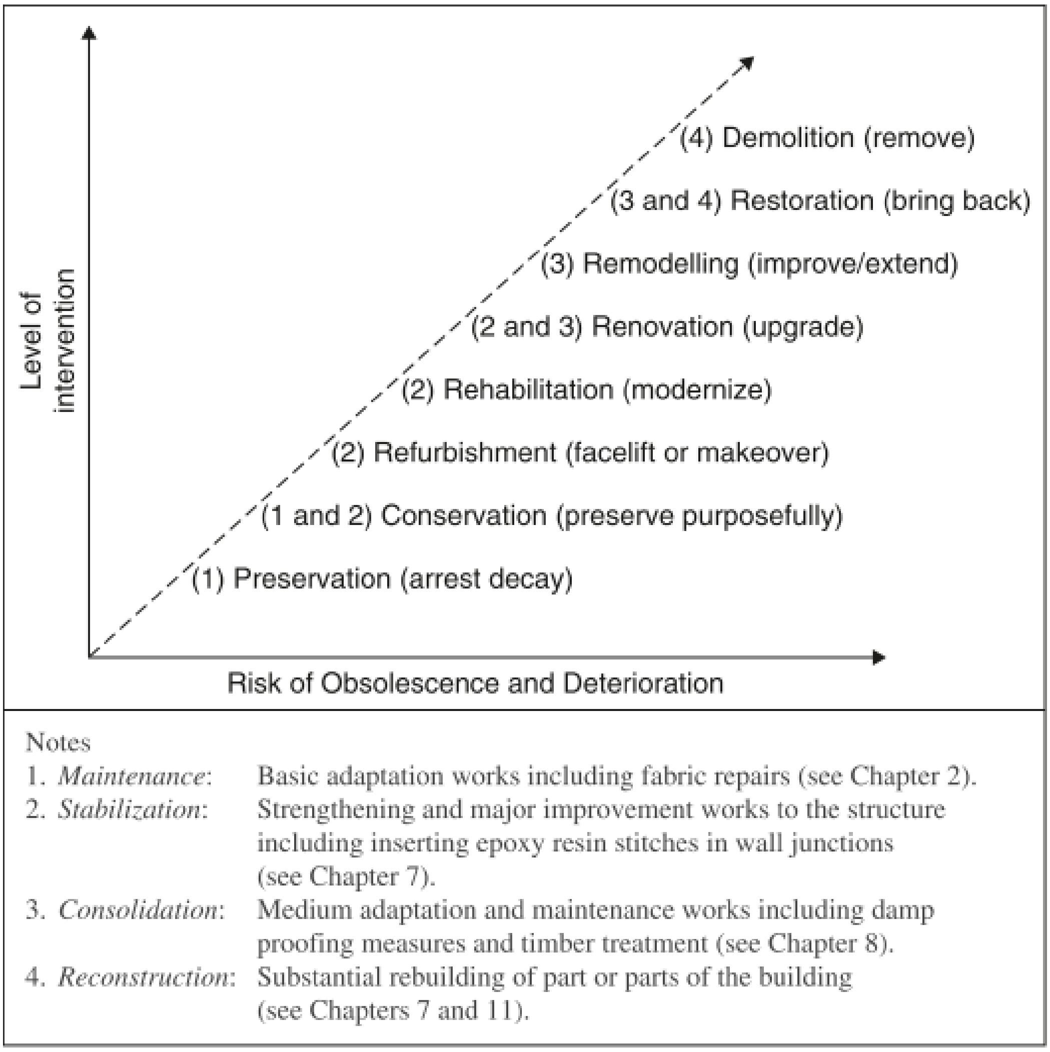
5 Appendix

5.1 Ranges of intervention

Figure 2: Ranges of intervention [Douglas, 2006]



5.2 Adaptability and Flexibility definitions and classification

Table 1: Definitions and categorisation in selected sources

Source	**Adaptability definition**	**Flexibility definition**	**Adaptability Classification**
Flexible housing [Till and Schneider, 2016]	Based around issues of use, covering spaces that can be used in a variety of ways, generally without making physical changes.	Involves issues of form and technique, is achieved by altering the physical fabric of the building, altering the physical fabric of the building [including] both internal and external changes, and both temporary changes and permanent changes	• Soft: refers to tactics which allow a certain indeterminacy • Hard: refers to elements that more specifically determine the way that the design may be used.
Building Adaptation [Douglas, 2006]	General capacity of a building to absorb minor and major change, includes different types and criteria	One of the criteria of adaptability: Enabling minor if not major shifts in space planning – to reconfigure the layout and make it more efficient	1. changes in function (e.g. conversion) 2. changes in size (e.g. extension/partial demolition) 3. changes in performance (e.g. refurbishment)
Adaptable architecture theory and practice [Schmidt and Austin, 2016]	The capacity of a building to accommodate effectively the evolving demands of its context, thus maximising its value through life.	N/A (the term omitted to avoid confusion)	1. Adjustable – change of task/user 2. Versatile – change of space 3. Refitable – change of performance 4. Convertible – change of use 5. Scalable – change of size 6. Movable – change of location
Flexibility and adaptability [Leaman and Bordass, 2004]	Infrequent, high magnitude changes	Short-term, low magnitude changes	N/A

5.3 Adaptability types according to [Schmidt and Austin, 2016]

1. Adjustable: Changing the task or user of a space, like adjustable furniture for different activities.
2. Versatile: Altering the spatial layout to suit different activities, ownership changes, or user numbers.
3. Refitable: Modifying a building's performance for reasons like legal shifts or environmental concerns.

4. Convertible: Changing a building's use, like converting offices to residential spaces, considering factors like storey height and structural grid.

5. Scalable: Expanding or reducing a building's size in response to user needs, market dynamics, or budget fluctuations.

6. Movable: Designing buildings for mobility, suitable for temporary uses like concert venues.

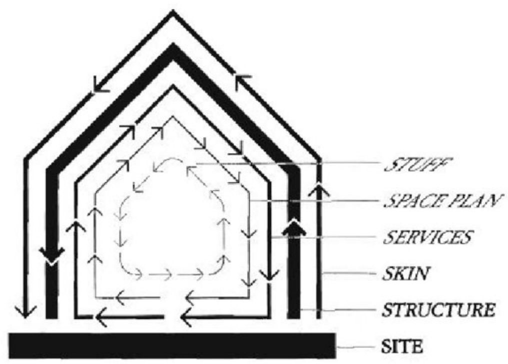
5.4 Elaborated Design Characteristics

This chapter has reorganized the principles from various sources such as "Flexible Housing".[Till and Schneider, 2016], "DfD. Design for Disassembly in the built environment: a guide to closed-loop design and building"[Brad Guy et al., 2008], the book "Adaptable Architecture, theory and practice"[Schmidt and Austin, 2016] and clustered them by the common concepts. The book "Adaptable Architecture, theory and practice" by [Schmidt and Austin, 2016] provided systematic indexing of the Design Strategies (DS...) and the connected Characteristics (CAR...). To allow seamless cross-referencing with the source, should the reader require that, the original indexing is detailed in Appendix 5.5.

Layers Designing in layers is stated in multiple sources as a fundamental principle that facilitates the adaptability of the building. This concept acknowledges that various layers of a building have differing lifespans and thus necessitate separation to facilitate timely replacement due to wear and tear or evolving demands. Traditional modern construction often interconnects these layers, leading to challenges where altering one layer may impact or even necessitate the destruction of others. The stratification of a building's layers, as per the widely cited framework by Stuart Brand, is as follows: Site (infinite lifespan); Structure (greater than 100 years); Skin (30-60 years); Services (dependent on maintenance needs); Space-plan (5-30 years); and Stuff (less than 10 years). (See Figure 3) [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Building design must prioritize component accessibility for easy replacement of elements with shorter lifespans without causing damage to other components. Implementations such as dropped ceilings or raised floors demonstrate how service elements can be accessed. However, this often requires sufficient floor-to-floor height. Such accessibility is vital as it allows service elements to be separated and accessed independently, enhancing the adaptability of the building.

Figure 3: Shearing Layers of Change (Brand, 1995).



Loose-fit The longest-living building layer (except for the site) and thus arguably the most important layer that predetermines the adaptability potential of the building is the load-bearing construction. Adaptable building design centres around a load-bearing construction that allows flexibility of the floorplan, which is crucial for enabling future modifications. The key to this adaptability lies in designing a generic frame that acts as the building's skeleton. This frame should be distinct from the infill, partitions, services, and external walls, ensuring that it does not predetermine their positions. The more open this frame, meaning the larger the open spans are, the greater the potential for future adaptability.[Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

One of the key aspects of this approach is the emphasis on non-loadbearing internal and partition walls. These walls should be designed to be easily removed or reconfigured without affecting the building's structural integrity or its building physics aspects. This approach allows for easier internal reorganization and the interchangeability of the floor plan. Loosely designed spaces also enable users to modify the space to fit their needs tighter, increasing the needs that are being met while acknowledging changing needs for changing users.[Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Overdesign capacity Designing a structure that anticipates an increase in loads in the future (through vertical expansion or the addition of floors and mezzanines) is a common example of overcapacity design. Not only does it provide more options for altering the building, but it also increases the chances of the building being compliant with future safety regulations, should they be altered. Designing increased floor-to-ceiling heights is beneficial as it allows for the installation of false ceilings, separate service runs, improved cooling, and increased natural light penetration. Additionally, double-height spaces provide the option for internal growth, such as incorporating mezzanine levels for added versatility. [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Circulation spaces, both inside and outside dwellings, are typically planned to occupy minimal space for efficiency. However, if designed thoughtfully with additional space, these areas can transform from mere passageways to social hubs. For example, wider external circulation areas can become informal sitting areas, enhancing the sociability of the space. Similarly, expanding internal circulation spaces can convert them from mere corridors to functional areas suitable for storage or even small rooms.[Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Simplicity and Legibility Simplicity and legibility are paramount in the design of adaptable buildings, especially when it comes to identifying load-bearing and non-load-bearing structural elements. Challenges often arise during adaptation when this differentiation is unclear. While designing in layers suggests clarity on what can and cannot be altered, there are instances where these layers become overly complicated, especially if they require specific manufacturers. [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Employing exposed structures that eliminate the need for false ceilings or concealed services can greatly increase separability. This approach not only provides more space and taller floor-to-floor heights but also enhances overall functionality and feasibility in building design Consolidating functionalities into a single component may appear cost-effective initially, but it can lead to unintended dependencies and complexities during modifications. This highlights the importance of deliberate and thoughtful design in the early stages. Using standardized components enhances quality through repetition and promotes interchangeability. It also minimizes the need for spare part storage, facilitates component replacement, and increases reusability. Standard columns, beams, and openings are typical examples of this approach. Modular coordination enhances the design process by employing planning grids that align furniture, partitions, and exteriors. This coordination not only facilitates the creation of standard room layouts but also simplifies the planning process. The use of standard grid systems, often in alignment with a structural grid, simplifies the subdivision and extension of spaces. This simplification promotes versatility in design and supports a non-specific, adaptable architectural image.

When designing, it is beneficial to create simple plans that can be deduced into linear or rectangular shapes. Incorporating a straightforward form with straight vertical and horizontal surfaces aids in maintaining a clear and legible structure. This approach not only simplifies the adaptation process but also ensures a coherent and functional design over time. [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Spatial planning This research aims to achieve adaptability in architectural design, particularly focusing on initial designs with a housing function. A key aspect of this goal is to provide the possibility for individual unit dwellings to be joined or divided. This capability is essential for transforming single-tenant spaces into accommodations suitable for multiple occupants. In designing joinable and divisible spaces, several critical factors must be considered, including service access, security, and spatial arrangement. A spatial plan is also a determinant of the ability of the building to effectively expand. The circulation plan is essential to allow seamless integration of the expansion into the existing plan.

The concept of typology patterns, which encapsulate trends and characteristics of specific periods, guides evidence-based designs. This approach is particularly relevant given the above-mentioned trend of reduced household sizes and the increasing demand for smaller dwellings. Rationalizing room sizes enhances interchangeability, a factor that is especially important in large-scale projects. Simultaneously, providing varied spatial sizes caters to a range of activities. Striking a balance between standardized and diverse room types often complements open-plan spaces. Grouping spatial zones by function further contributes creation of adaptable spaces. This includes segregating fixed areas like vertical circulation or wet spaces in residential developments. Utilizing standard locations for hidden service elements exemplifies simplicity in design. Standardized fittings, fixtures, and modular storage placed in standardized grid locations further reinforce this concept of adaptability and efficient space utilization.[Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016]

Design for Disassembly Design for Disassembly (DfD) emerges as a crucial design consideration when aiming to create adaptable buildings. It's not only about allowing change but also facilitating the dismantling of the building efficiently and sustainably, with the goal of allowing the dismantled elements to be reused. DfD is effectively implemented through specific structural forms that promote ease of disassembly and reconfiguration, essential for the longevity and adaptability of the structure. Certain decisions have to be made right from the beginning of the design process. The following section repeats some of the adaptability characteristics that are mentioned above but now relates them to the DfD philosophy, emphasizing its relevance. The potential for the construction to be demountable is to a great extent dependent on the correct choice of material and material treatments, as it influences the ease of the disassembly process and the subsequent reuse or recycle. It is important to minimize the different types of materials that are being used as it reduces the complexity of the construction and the separation process.

Correlating with the principle of design in layers, it is also important to avoid composite materials and inseparable elements assembled from different materials, as those are harder to separate and later recycle. Separating the structure from the cladding increases adaptability and aids in distinguishing between non-structural and structural deconstruction aspects. It is also best to not cover the connections by secondary finishes as it makes it difficult to later find these connections when disassembling. Similar to the separation of materials, the systems (Mechanical, Electrical and Plumbing) should also not be tangled into host assemblies, to ease repair, replacement, reuse and recycling. All materials, tools and methods must be well documented by utilising ”material passports”, labelling the connections and creating a deconstruction plan. A grid-like post and beam layout (loadbearing columns instead of walls) is central to DfD, simplifying the design and concentrating the structure at fewer points or planes. This approach is particularly effective in buildings with large open spans and external load-bearing elements, as non-loadbearing partitions are easier to remove and reconfigure. The visual clarity offered by a post and beam framework, characterized by visible joints and minimal dividing elements, indicates the potential for straightforward disassembly, which is essential for adaptability. Employing a standard structural grid allows for uniform sizes of recoverable materials, while a wide structural grid maximizes non-structural wall elements, further contributing to the building's adaptability. Additionally, the use of lightweight materials and components, which can be easily handled by human labour or smaller equipment, simplifies the disassembly process and reduces reliance on heavy machinery. The choice of construction elements plays a pivotal role and should be influenced by the expected machinery used during the construction and deconstruction phases. Larger panels or structural components are suitable for scenarios involving heavy machinery. In contrast, environments anticipating less mechanical intervention should opt for smaller, more numerous components.

A critical strategy in DfD is to minimize the variety of components, thereby increasing the quantities of similar recoverable components. The design should take advantage of using standard and limited palettes of connectors and fasteners to reduce the number of needed tools and simplify the switch between them. This not only enhances the efficiency of the deconstruction process but also contributes to sustainability. Finally, the accent in this approach often lies in creating easily reversible, mechanical connections which often suggest utilizing bolted, screwed, and nailed connections. However, these joints and connections should be designed to withstand repeated assembly and disassembly. To minimize the need for destructive disassembly methods, elements should be designed with adequate allowances. [Schmidt and Austin, 2016] [Till and Schneider, 2016] [Ross et al., 2016] [Brad Guy et al., 2008]

Design Tactics

Design for durability The selection of materials in construction plays an important role in ensuring sustainability and adaptability. Materials that are resilient to damage or decay are highly desirable in this context. Such materials not only exemplify durability but also often correlate with straightforward construction methods. Additionally, aligning material choices with local industries and vernacular practices ensures their availability for future alterations, reinforcing the commitment to sustainable construction practices. [Schmidt and Austin, 2016]

Prefabrication Another significant aspect of sustainable construction is the method of production. Employing off-site production methods, such as off-site prefabrication, is a strategy that enhances the construction process. Prefabrication promotes cleanliness and precision, contributing significantly to the coherence of the overall system. These methods, characterized by their efficiency and precision, align well with contemporary construction practices that prioritize sustainability and adaptability. [Schmidt and Austin, 2016]

Building function Maximizing building use is essential for enhancing the functionality and financial viability of a structure. This concept focuses on increasing the time frame in which the building is utilized throughout the day, week, and year. This approach allows the building to cater to various demographics at different times, enhancing its utilization and relevance. However, employing multiple and mixed tenures within a building can introduce complexities, especially when tenants operate during different hours of the day or week. This necessitates the implementation of separate access and services to accommodate the diverse needs of the occupants. Therefore, the design must incorporate the isolatable characteristic, allowing for efficient and flexible use of the building spaces while addressing the varied requirements of its users.[Schmidt and Austin, 2016]

Information The first step in adapting the building is an investigation of the status of the existing structure. This can be problematic when there is no clear information on the building. Therefore, it is also important to establish detailed documentation, which would include clear floorplans, reports, and maintenance records. This goes hand in hand with utilizing BIM modelling practices. Material passports are another important part of detailed information and documentation. [Schmidt and Austin, 2016] [Ross et al., 2016] According to Van Capelleveen et al. A material passport, also known as a product passport, is a digital tool that provides detailed information about a specific product. This includes its entire life cycle, from creation to disposal, and focuses on understanding its sustainability, its estimated value in this context, and potential uses for the product and its components at the end of its life cycle.[Van Capelleveen et al., 2023] Finally if the design is created for disassembly, labelling the connections and creating a deconstruction plan is essential to enable success. [Brad Guy et al., 2008]

The section discussed various design characteristics that increase the potential of the building to be adaptable. The characteristics have been studied and their effectiveness has been evaluated by several scholars through various methods. In one particular study, the author compiled a list of ”Adaptability enablers” and then invited 20 experienced design and construction professionals to participate in a survey which ranked the enablers based on their effectiveness. The experts consulted in the survey identified the most impactful design facilitators as precise building information (Information), additional capacity in building systems (Overdesign capacity), segregating building systems based on their replacement frequency (Layers), and interior spaces with easily removable partitions (Loose-fit). [Ross et al., 2016]

5.5 Selected Design Strategies (DS) and Characteristics (CAR) organised according to the source ”Adaptive architecture: theory and practice” [Schmidt and Austin, 2016]

DS1 Modularity DS1 emphasizes the division of a structure into distinct functional entities, enabling flexibility and adaptability.

One key aspect is Reversibility (CAR 1), highlighting a construction’s ability to be disassembled into its constituent parts with minimal or no damage. Interior walls, preferably non-loading bearing partitions, strike a balance between highly restrictive load-bearing walls and costly demountable ones, especially for infrequent changes.

While consolidating functionalities in a single component may initially reduce costs, it often results in unintended dependencies and complexities during modifications, emphasizing the need for careful consideration.

Component Accessibility (CAR 3) focuses on easy access to building components without damaging others. Examples, like dropped ceilings or raised floors, illustrate how service elements can be accessed, although this often requires adequate floor-to-floor height. This accessibility ensures service elements can be separated and accessed without disrupting other layers, promoting adaptability in building design.

DS3 Long life DS3, focusing on Long life, emphasizes the durability of physical building components for extended use.

Materials resilient to damage or decay (CAR 10) exemplify this approach. Additionally, durable materials correlate with straightforward construction methods (CAR 19) and can align with local industries (CAR 15), ensuring availability for future alterations—a testament to sustainable construction practices.

Overdesign (CAR 14), often seen in structures accommodating additional loads or extra floors, and service elements with excess capacity, typifies this strategy. These practices, while enhancing longevity, can sometimes lead to unnecessary or excessive construction, warranting careful consideration during the design phase.

DS4 Simplicity and Legibility DS4, emphasizing Simplicity and Legibility, underscores straightforward building design principles.

Standardized components (CAR 16) enhance quality through repetition, promoting interchangeability, minimizing spare part storage, facilitating component replacement, and increasing reusability. Standard columns, beams, and openings exemplify this approach.

Utilizing standard locations for hidden service elements (CAR 17) showcases simplicity. Standardized fittings, fixtures, and modular storage, placed in standardized grid locations, further illustrate this concept.

Off-site construction's cleanliness and precision (CAR 18) contribute to improved system coherence. Simple construction methods (CAR 19), like exposed structures eliminating the need for false ceilings or concealed services, increase separability and accessibility (CAR 3 and 4). This simplicity offers feasibility, more space, and taller floor-to-floor heights, enhancing overall functionality.

DS5 - Loose fit DS5, centered on Loose fit, advocates for open, adaptable spaces that can be tailored as needed.

Open spaces (CAR 20) offer versatility for customization (CAR 24), often achieved by removing permanent obstacles. Varying clear spans, like 4m to 8m in residential designs and 15-20m in offices, exemplify this adaptability. Top floors typically have fewer structural restrictions, allowing greater design freedom.

Cost considerations (CAR 22) often limit oversized spaces, as taller floor-to-ceiling heights increase capital costs. However, these heights offer flexibility for false ceilings, separate service runs, improved cooling, and increased natural light penetration (CAR 3, 4, 12, 39).

Determining an oversized space's size varies with its intended use; residential high ceilings may exceed 2.9m, while office spaces might surpass 3.5m. Double-height spaces also enable internal growth, incorporating mezzanine levels (CAR 40) for added versatility.

DS6 Spatial planning DS6, focusing on Spatial Planning, delves into the strategic utilization of space for optimized functionality and adaptability.

Typology patterns (CAR 23) encapsulate trends and characteristics specific to certain periods, guiding evidence-based designs. Rationalizing room sizes (CAR 27) enhances interchangeability, especially in large-scale projects like hospitals. Providing varied spatial sizes (CAR 28) caters to diverse activities, balancing standardized and diverse room types, often complementing open plan spaces (CAR 20).

Joinable and divisible spaces (CAR 24) are crucial when dividing single-tenant spaces for multiple occupants, considering service, access, and security. Spatial zones, grouped by function, create adaptable spaces, particularly by segregating fixed areas like vertical circulation or wet spaces in residential developments.

Modular coordination (CAR 25) typically employs planning grids aligning furniture, partitions, and exteriors, enhancing standard room layouts (CAR 27) and facilitating simple plans (CAR 32). Standard grid systems, often aligned with a structural grid (CAR 33), simplify subdivision and extension, promoting versatility in design (CAR 34) and a non-specific image (CAR 54).

DS9 - Maximise Building Use DS9 emphasizes expanding a building's usage across varying time frames for increased operational efficiency.

Mixed-use designs enhance a building's financial viability by accommodating diverse demographics at different times. However, multiple and mixed tenures can complicate building systems, requiring separate access and services for tenants with varying schedules. Implementing isolatable characteristics addresses these challenges.

Success with multiple access points relies on appropriate physical linkage and security measures (CAR 24) to facilitate joining/dividing spaces for different purposes, ensuring seamless transitions between varied uses within the building.

Based on the above outlined principles one can derive the following guidelines for the design of the building to follow (the principles that are relevant for the design of the structure are in bold):

1. **Ensure modules allow for combination but also enable reversibility and disassembly (CAR 1).**
2. Facilitate access to components (CAR 3).
3. **Separate load-bearing structures from non-load-bearing partition walls (**CAR 4).
4. **Use resilient, durable materials in construction** (CAR 10).
5. **Design with potential beyond designated capacity to allow adaptability to changing conditions** (CAR 14).
6. **Utilize standardized components throughout the building** (CAR 16).
7. Research and implement standardized locations for service elements on the grid (CAR 17).
8. **Employ off-site production methods for construction** (CAR 18).
9. **Implement simple construction methods and structural systems** (CAR 19).
10. **Design open spaces with maximum spans for versatility** (CAR 20).
11. **Incorporate extra height in oversized spaces for increased adaptability** (CAR 39).
12. Base design decisions on typology patterns (CAR 23).
13. **Create joinable and divisible spaces to accommodate varying uses** (CAR 23).
14. **Utilize modular coordination systems and standard grids** (CAR 25, 33).
15. Optimize room sizes with some variety for adaptability (CAR 27, 28).
16. Establish spatial zones and clusters within the building (CAR 30, 31).
17. **Design simple plans, deducible into linear/rectangular shapes** (CAR 32).
18. **Incorporate a simple form with straight vertical and horizontal surfaces** (CAR 33).
19. Design multi-functional spaces to cater to various purposes (CAR 43).
20. Create isolated parts within the building structure (CAR 48).
21. Establish multiple access points for different uses (CAR 49).

5.6 Timber standard stock

Figure 4: GLM standard beam crossesction [Mayr Melnhof Holz, 2022]

Standard cross-sections

We keep the following standard cross-sections in stock at Mayr-Melnhof Holz:

Height (in cm) ▼	Widths (in cm) ▶									
	6	8	10	12	14	16	18	20	22	24
10		8/10	10/10							
12	6/12	8/12		12/12						
14		8/14			14/14					
16		8/16	10/16	12/16	14/16	16/16				
18							18/18			
20	6/20	8/20	10/20	12/20	14/20	16/20	18/20	20/20		
22									22/22	
24		8/24	10/24	12/24	14/24	16/24	18/24	20/24		24/24
28				12/28	14/28	16/28	18/28	20/28		
32		8/32			14/32	16/32	18/32	20/32		
36						16/36		20/36		
40								20/40		
44										
48										

Standard cross-sections in standard lengths 12 m, 13.50 m, 16 m and 18 m are always available in film-wrapped units.

Figure 5: LVL standard beam crossesction