SPATIAL ADAPTABILITY IN THE CONTEXT OF MULTIFUNCTIONAL TIMBER HIGH-RISE BUILDING

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ABSTRACT

The sustainability of the building industry and the increasing demand for new buildings creates an opportunity where materiality and adaptability of the build environment needs to be reassessed in order to answer to the following issues. The research paper delves into the subject of adaptability in the built environment and checks the influence of materiality on such topics. The research scope touches on spatial adaptability in addition to the high-rise oriented case study where mass-timber buildings with potential of altering its function in the future. The result of the research will provide a quantifiable score of spatial adaptability for each case study that will indicate the degree of spatial adaptability.

Keywords: *adaptability, timber-based structure, spatial adaptability, Open Building, multi-scenario building, MASS timber high-rise.*

I. INTRODUCTION

The subject of making the building industry more sustainable is as influential as ever. Numerous architectural and construction companies are pledging their sustainable goals for the following years. However, the rising global population and mass immigration from the villages to the cities only deepens the already existing concern of unsustainable building industry since the demand for new structures is consistently growing.

According to the UN (GSR,2021) report the construction industry in 2020 was responsible for 36% of global energy consumption and 37% of energy-related CO_2 emissions which leaves a lot of room for improvement. Since the most common building materials like steel or concrete are great polluters that contribute largely to the carbon footprint of the building industry, there is a high demand for the new versatile constructing material that could level with the endurance and strength of the latter materials.

In the last 30 years, timber-based construction has seen its renaissance due to the new advancements in timber technology like compositing, innovative joinery, advanced adhesives and digital tectonics that elevates timber to be as strong as steel or concrete structure. Only recently has there been a rapid popularization of the idea of timber based high-rise like, the Treet in Bergen completed in 2015 or Brock Commons in Vancouver completed in 2017 both of which were the world's tallest timber-based buildings respectively. The timber-based structure allows for a greater degree of prefabrication which makes the construction process not only shorter but also way quieter and cost-efficient. Moreover, due to the lightness of wood, the foundations are also relatively more shallow which improves the cost efficiency. In addition, the ability to store CO_2 is a very appealing property that can potentially reverse the CO_2 emission trend in the building industry.

On the other hand, the increasing demand for new buildings creates an opportunity to rethink how our buildings should be utilized in the most efficient way. With the technological progress of the building industry, the approach to a building as an entity has changed significantly. The rapid socio-economic changes have often led to various stages of redundancy no matter if it were for the residential neighborhoods, industrial buildings or entertainment facilities. However, most of the built environment consists of rigid monofunctional buildings designed for a specific purpose without any valid plan for change or dismantling process in the future. Even the contemporary multifunctional buildings often have functions rigidly embedded into the tissue of the building without any room for further adaptation. Such a situation is also reinforced by the nature of the structural materials like steel and concrete, which are difficult to adapt to the new needs. As a result, many buildings deteriorate due to lack of a plan for adaptation and are being left out due to the ineffectiveness of their properties and being allocated for reconstruction or worse, demolition which generates a significant amount of waste and pollution.

Clearly, the adaptability of a building is not only a functionality aspect but also plays a major role in emission reduction policy to fight the environmental degradation that is caused by the building industry. Combined with sustainable materiality it could potentially be the answer to the changing reality of the built environment. The aim of this research is to study the adaptability strategies and check if it can be evaluated in a scientific way and determine the adaptability properties of the timber based structures in order to use the findings in the design phase of the graduation.

1.1. Research questions

What combination of timber-based prefabricated modules would optimize the spatial adaptability of multipurpose high-rise building?
Sub questions:
1. What are the main design strategies for adaptable architecture?
2. What is spatial adaptability and how to evaluate it in the context of timber based multifunctional high-rise building?
3. What kind of modular timber-based prefabricated modules are most suitable for interior spatial flexibility and adaptive architecture?

II. METHODOLOGY

The research paper is written as a part of the graduation project in Architectural Engineering Studio at TU Delft. It was conducted on two parallel fronts; The first one is based on literary research of the current strategies enhancing the adaptability of the building while defining the spatial adaptability and checking how to evaluate it, which would further provide answers for the first two sub questions. In order to answer the main research question and the third sub question the second research front is based on the case study analysis, to evaluate existing timber based structures through spatial adaptability criteria and check which combination of mass timber modules can potentially optimize the spatial adaptability. The case study examples has been chosen based on specific criteria like:

Function – dwelling or multifunctional with dwellings included
Structure – prefabricated/modular
Height – mid/high rise
Structural materiality – predominant timber based materials
Completion date - Due to the relatively recent popularization of timber based high rise structures all the case study examples are from the last 15 years.

The literature research and the case study was mainly conducted using TU Delft Library resources and database with the subsidiary use of the Google Scholar and ResearchGate. Although the theme of adaptability in architecture is widely spread across the scientific literature, most of them deal in describing different typologies and strategies that would enhance such properties rather than provide coherent evaluation systems that would grade various strategies. However, the book, Adaptable Architecture: Theory and Practice by R.Schmidt III and S.Austin(2016) acknowledges this specific issue with adaptable architecture strategies and showcases a new adaptability typology that would inform and help the designers to decide which one would be most suited for their design purposes. This particular issue has been further elaborated on in the next chapter (see Chapter III), hence the evaluation framework was mainly based on the work of R.Schmidt III and S.Austin(2016), where they propose an evaluation system based on the DSM (Design Structure Matrix) which can deliver quantitative results without using sophisticated software. The precise technical information about the subject of the case study is limited due to the innovative character of mass timber high-rise building. The vast majority of timber high-rise buildings that can be researched is currently under development and therefore cannot be included into any scientific work. Due to the limited resources currently available the technical aspect of the research paper is based mainly on the reference book Manual of Multi-Story Timber Construction by H.Kaufmann, S.Krötsch and S.Winter(2018) and Tall Wood Buildings by M. Green and J. Taggart(2017) and catalogues of ThinkWood curated by the American Wood Council, NaturallyWood developed by Forestry Innovation Investment from British Columbia.

III. The Blurred Definition of Adaptable Architecture

The term adaptable architecture has recently become a buzzword that could potentially help to solve sustainability and functionality issues that we face today. According to R.Schmidt III and S.Austin(2016) „Adaptability then is concerned with the capacity to adjust or be adjusted to suit new situations." Furthermore, the term adaptable architecture would suggest a design that can accommodate numerous changes. There are many other phrases that are used alternatively like flexible architecture, adjustable architecture or convertible architecture. However, the exact definition of such phrases tend to be blurred in terms of its meaning in architecture. Architects and developers often use such terms as synonyms as Olsson and Hansen(2010) describe, „either used different terminology or the same terminology with different meanings. Each of the projects tended to develop its own terminology." This phenomenon of loose terminology can be confusing at times and it can lead to misconceptions about the adaptability of the built environment. Since the definitions are blurred and many literature examples tend to differentiate those terms through different stages of adaptability e.g. N.J. Habraken(2008) explains that "words like 'adaptability', 'flexibility', and 'polyvalence' have multiple and often overlapping meanings that make it virtually impossible to come up with a vocabulary acceptable to everybody". In effect many researchers and academics created a whole constellation of closely related phrases that named different types, strategies and levels of adaptability in architecture. As the R.Schmidt III and S.Austin(2016) depicts in the graphic below where they asked sixty practitioners to come up with words they associate with adaptability.

Although there are so many terms associated with it, the concept of a fully adaptable building is hardly possible to achieve due to the tremendous amount of variable changes that might occur during the life cycle of a building. The time aspect is also tricky since there is no clear indication of how long the building will last. There are numerous examples of buildings that were designed for a shorter period of time yet they were not dismantled in time generating additional costs for maintenance, e.g. most of the soviet era prefabricated blocks of flats in the eastern Europe designed and built in a hurry to be a temporary solution due to the housing crisis after the WWII.

Fig.1.1

The concept of a fully adaptable building is not only impossible to achieve but it is also quite unnecessary. According to De Neufville et al.(2008), „flexibility is only valuable if it is exercised effectively (when the time is right) and efficiently (at acceptable cost and disruption)". Even if a building could potentially accommodate all the different adaptable solutions it would be in the end, a waste of resources and time since not every option can be used at the same time. Schmidt III and S. Austing(2016) Instead we can anticipate different types of change and evaluate which ones can be useful for the needs of the project.

In order to plan a viable strategy for adaptable building the typology of change must be acknowledged and categorized. According to P.Russell and S.Moffatt(2001) adaptability can be broken down into three main categories like: flexibility, convertibility and expandability, where flexibility means applying small changes to the spatial layout, convertibility means the change in use within the building and expandability is adding on the quantity of space in the building.

3.1. The Current Adaptability Concept

At the same time there are two main concepts that are well known and have been tested throughout the time although the results are not without ambiguity. Those concepts are: Open Building and Shearing Layers. All of which exist on the same theoretical plane of making the adaptable building technically possible. Such theories and concepts are often overlapping in its meaning and there is no clear consensus among the scholars on what it actually means to design an adaptable building or in other words there are multiple overlapping answers to that question and there is no clear indication which one is the most usable.

3.1.1 Open building

This concept was originated in the 1960's when Europe was in a dire need of new housing units after the WWII. Due to the scale of the problem many housing units were built as a copy of each other without any consideration for the neighborhoods architectural value. N.J. Habraken(1972) in his book, *Supports: An alternative to mass housing*, criticized such notion and proposed a system that could solve such problem. In his view the building was divided into two elements. The „base building" that was for the investor to make the design decision to optimize the costs and the flexible infill „fit out" that was subjected to the user needs that can change over time. The base building would consist of the structural elements which is the rigid part of the building „while the infill or "fit-out" is formed by the flexible parts that are exposed to recurrent changes" Askar, Bragança, Gervásio(2021) Although the Open Building concept is well known to the academics it was tested only on several occasions, primarily in Japan and the Netherlands, most of which failed in proving the effectiveness of the theory. One of the most notable example of such project is Quinta Monroy by Alejandro Aravena, built in Chile.

Recently however, the Open Building concept has been reformulated by the Dutch team of professionals from the various architectural companies. Basing on the original concept of Habraken and updated it by the Shearing layers concept by S.Brand they have redesigned the idea of ownership scenarios which creates new field for co-living and co-creation of the space that adapts to its inhabitants needs. There are multiple contemporary examples that are using this refreshed idea which creates a field for investigations and opportunity to further develop this concept.

3.1.2 Shearing Layers

Arguably the most common strategy that enables adaptability introduced by S.Brand in a book *How buildings learn* in 1994. He proposed a model that consists of multiple hierarchal layers (site, structure, skin, services, space plan, and stuff) with different timescales that make it a dynamic system that transforms itself overtime. Askar, Bragança, Gervásio(2021). Brand proposed that the elements of a shorter lifetime would not directly interact with components of the longer lifespan and durability. That solution allows for an easy disassemble and rearrangement of components in order to adapt to the current need.

Upon that theory many scholars have built their own interpretations of adaptable architecture by adding additional theoretical layers of components or by proposing different ways of decomposition of a building in order to ease the transformation. S.Isaac(2016) proposed utilizing the existing model of BIM that would automate decomposition and create a graph methodology in order to optimize the process of design for adaptability. This idea could quickly take over since BIM is already widely spread around the building industry, however such software needs further development in order to prove its capabilities.

3.2. The Spectrum of Adaptability

Relatively recently R.Schmidt III and S.Austing(2016) came up with an interesting proposition to divide adaptability into sub-categories where the type of change is assigned to the type of adaptability. Due to the common misconceptions about adaptability in architecture in various literature they have proposed a unified categorization of the adaptability in order to „improve on the imprecision in language" R.Schmidt III and S.Austing(2016), since there is no clear consensus on the definition of adaptability. The categorization was created in order to establish a framework of design tactics and specific characteristics that are instrumental for adaptability in architecture. Those are mainly based on existing examples of such buildings that have been proven overtime its capabilities and qualities. The whole framework is based firstly on the premise that the adaptability is not really a characteristic trait of the building but rather a spectrum of design choices and spatial layouts that enable multiple changes throughout its lifecycle. Presented below are the categories of adaptability that were proposed by them:

Adjustable – change of task/user
Versatile – change of space
Refitable – change of performance
Convertible – change of use
Scalable – change of size
Movable – change of location

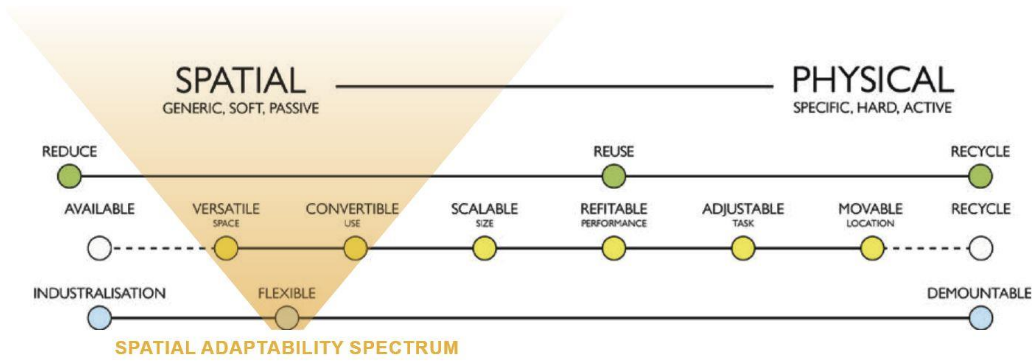


Fig.1.2

According to R.Schmidr III and S.Austing(2016) one of the most common categorization found in literature is based on the spatial-physical aspect of change. Although the spatial aspects tend to be more generic and passive in its nature it does affect more theoretical layers than the physical aspect that usually affect only a few ones. In result the spatial adaptability is effective in changing the entire building characteristics while the physical one is more focused on precise change that alter the performance of the building.

3.3. What is Spatial Adaptability?

The scope of this research delves particularly in the spatial aspect of adaptability in architecture, however the typical strategies for adaptability do not provide guidelines for human-centric changes and are more connected to the performance based transformations of a building. The spatial adaptability however, is concerned with the more generic approach that is capable of adapting to certain situations on multiple timelines. From the everyday layout changes to the functional changes during the lifecycle of a building. Both timelines are strictly connected with the needs of the user, regardless of the inherent technical performance of the building.

In this research the categorization developed by R.Schmidr III and S.Austing will be used to create a framework of typologies of adaptability. Through the distinction above a typology can be defined that affects the spatial aspect of adaptability therefore it is safe to assume that the spatial adaptability spectrum would consist of the characteristics of versatility and convertibility alike. That distinction would provide an indication of which design tactics in particular should be taken in order to provide the spatial adaptability qualities. The characteristics and physical properties of each will help to set an evaluation framework on which the timber based buildings will be graded.

3.3.1 Versatility - short term change

This is one of the most common types of adaptability. It deals with the layout of space that can be changed according to the needs of the users. „Such changes may be brought about by variations in activities, organizational structure/philosophy, ownership or occupant." R.Schmidt III and S.Austin(2016) It can help to avoid high-cost refits to alter the performance of the space and reduce the time needed to implement new solutions. Such spaces are specifically designed to be rearranged for different types of activities, number of users or work patterns. The changes are specifically based on the everyday needs of the users, the changes themselves are predominantly human-centric and does not affect the technical performance of the building. However, the physical aspects of the building can enhance such capabilities like large structural spans, location of services and movable partition walls.

3.3.2 Convertibility - long term change

It refers to the change of use of the space that can occur due to the ever changing demand of the market, social demands, ownership or occupancy. Although many buildings have seen its conversion to a different function most of them haven't been designed to be converted to begin with e.g. Battersea Power Station. This type of adaptability presumes the inevitable conversion of function and it is addressing that through specific design that enables different functional adaptations. Although caused by the human-centric need for different function it is achieved by various methods from adding new components to changing the spatial layout. Usually the conversion works better when it is only in one direction e.g. office to residential. The conversation is usually easier when the typology of a structure is similar throughout the entire building. Another physical aspects are: taller floor heights, higher load bearing floor capabilities and regular structural grid.

IV. EVALUATION FRAMEWORK

After establishing what spatial adaptability is, the evaluation of the adaptable properties of timber based structures can be conducted, however such evaluation is a complicated task for numerous reasons. Beginning with the previously described blurred definition of adaptability that changes from one piece of literature to another. Then there is an issue of an objective evaluation system and cost effectiveness of such adaptability. In a way, through technological advancements every building can potentially become adaptable, the question remains at what cost. However, the point of pursuing the adaptability concept is to design in such a way that the building can change its properties relatively easily. It is focused on reliable rules of thumb that can predict and accommodate possible changes, lowering possible costs for future refits.

Before the digital revolution the evaluation part was strictly subjective to the scholars experience and view on the topic. Now, however, there have been developed specialistic software that can calculate the adaptability of any building. One of the notable examples is Flexis, a Dutch software which is capable of examining and rating the performance of a building at various scales. Another example of similar software is the Use Comparator developed by UCL in the 1990's, however it was rather a decision making tool than the adaptability evaluation program. However, none of them made it to the mainstream built industry in order to lower the cost and optimize the design. Due to the complexity of such software and the steep learning curve it seems not suitable for this research to pursue this path.

On the other hand, a different approach can be found in the work of R.Schmidt III and S.Austin(2016) where they created a meta-model (FIG.3) that is specifically designed to help setting the goals for adaptability, divided into subcategories that were mentioned in the last chapter. The model is utilizing their findings about dependencies between the design tactics and adaptability typology. Instead of evaluating system, the authors are showing the cause and effect for numerous characteristics of a building which are based on the case study about architectural adaptability.

The model is divided between the types of adaptability and set on the timescale that informs about the amount of time needed for each type to be achieved. Each type has assigned design tactics that serve as enablers of adaptability. Through the extensive research among the professionals and case studies R.Schmidt III and S.Austin have created a framework of dependencies that assigned the design tactics to specific characteristics. However there is no clear guidance on how to evaluate adaptability in architecture. The meta-model proposed in their book is more of a schematic to categorize the characteristics and design tactics with each other. For the purpose of the research, a simplified grading system is proposed that identifies the level of dependencies between the characteristics of spatial adaptability and the physical aspects of timber based structures. The results will help to identify and use the design strategies that will enhance the spatial adaptability in my design phase. Below the meta-model showing the typology of adaptability with assigned design tactics (in black).

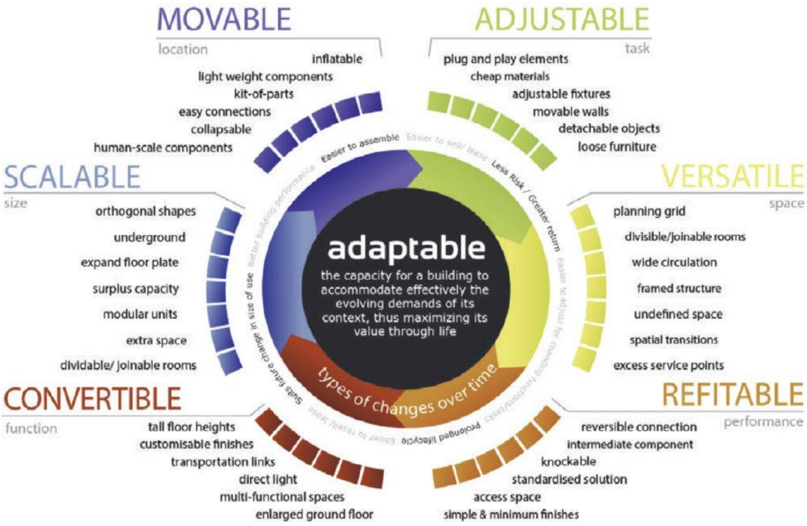


Fig.1.3

4.1. Criteria

The criteria of the evaluation process are taken directly from the framework of dependencies mentioned earlier and are matched with the spatial types of adaptability. Through that the specific design tactics are revealed and the specific characteristics are assigned to those tactics. The characteristics can serve as the criteria for evaluating the degree of spatial adaptability in order to answer the main research question. This framework of evaluation will allow to cross check the existing timber based buildings that are similar to the project objective and will evaluate its components and layout strategies through case studies. Below presented are the design strategies and corresponding characteristics, the naming and signage order has been preserved from the original content table from R.Schmidt III and S.Austin(2016) in order to avoid confusion. The overall list of design tactics *(DT)* and characteristics *(CAR)* can be found in **[Appendix 2].**

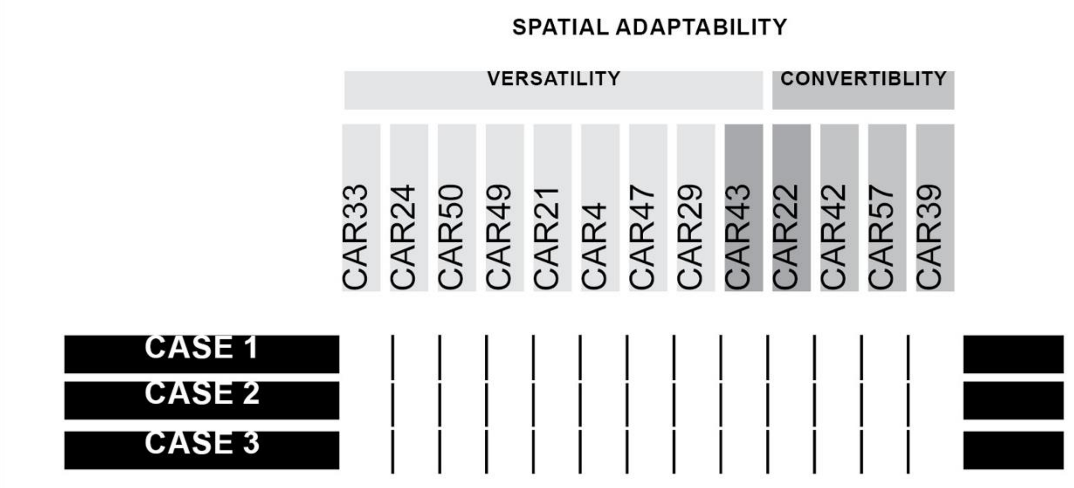
Versatility:
planning grid *DT78 - CAR33*
divisible/joinable space *DT55 - CAR24*
wide circulation *DT45 - CAR21, CAR22, CAR43, CAR50*
framed structure *DT7 - CAR4*
undefined space *DT47 - CAR21, CAR43, CAR47*
spatial transitions *DT68 - CAR29*
excess service points *DT115 - CAR49*

Convertibility:
tall floor heights *DT48 - CAR22*
customizable finishes *DT104 - CAR42*
transportation links *DT128 - CAR57*
direct light *DT93 - CAR39*
multifunctional spaces *DT105 - CAR43*
enlarged ground floor *DT49 - CAR22*

Characteristics description:
CAR33 - standardized dimensions with few anomalies
CAR24 - space that can be joined or divided to support multiple spatial configurations
CAR50 - physical connections between spaces
CAR43 - space that can be used for multiple uses
CAR21 - spaces typically not defined in the brief, but are necessary for functional support
CAR22 - space that is sized larger than the market standard or functional necessity in plan or section
CAR4 - separation of functions into different constituting parts; 1:1 function to component relationship
CAR47 - space that is shared by multiple individuals or organizations
CAR42 - usable 'finished' space that is designed to be decorated or appropriated by the user
CAR57 - multiple transportation options, a favorable climate and ample density
CAR39 - capacity for the majority of the spaces to be daylit
CAR43 - multifunctional spaces - space that can be used for multiple uses
CAR29 - Spatial ambiguity - blurred boundaries between interior and/or exterior spatial uses through soft boundaries or proximity
CAR49 - Multiple access points - provision of multiple entry points that can serve different uses or users

4.2. Grading System

The grading system will consist of a table of dependencies between the case studies and the characteristics described previously. The degree of dependency will be graded with equivalent mark. Inspired by the works of R.Schmidt III and S.Austin(2016) where they used a static version of the DSM(Design Structure Matrix) in order to check the dependencies between the adaptability typology, design strategies and characteristics. A simplified grading system is proposed, which utilizes a number that would grade the strength of connection between the spatial adaptability characteristics and the existing timber based buildings to find out which combination of timber based modules can enhance spatial adaptability. The grading system assigns 1 point where the connection between the characteristics and the case study is strong and/or applicable, 0,5 a point where the connection between is partly significant and 0 points when is nonexistent. The result will yield a score that would provide an insight on the adaptability capabilities of various timber based structures.



An example of evaluation framework Table 1.1

V. CASE STUDY

In this part of the research paper will introduce and analyze notable examples of mass timber high-rise and will check if their materiality and design contribute to the spatial adaptability properties. Since there is no specific grading system that would allow for scientific evaluation of a structure in terms of spatial adaptability, the simplified system proposed here will provide some insight towards the correlation between the timber based structural systems and the spatial adaptability properties by comparing and contrasting the specific characteristics and design tactics with the properties of each case. The analysis will use the previously mentioned evaluation framework that would showcase specific design choices and characteristics and grade them in order to check how spatial adaptability can be enhanced by timber-based structural systems. The examples for this case study has been chosen using specific selection criteria like:

Function – dwelling or multifunctional with dwellings included
Structure – prefabricated/modular
Height – mid/high rise
Structural materiality – predominant timber based materials
Completion date **-** Due to the relatively recent popularization of timber based high rise structures all the case study examples are from the last 15 years.

Brock Commons Tallwood House Fig.1.4

5.1. Case 1 – Brock Commons Tallwood House

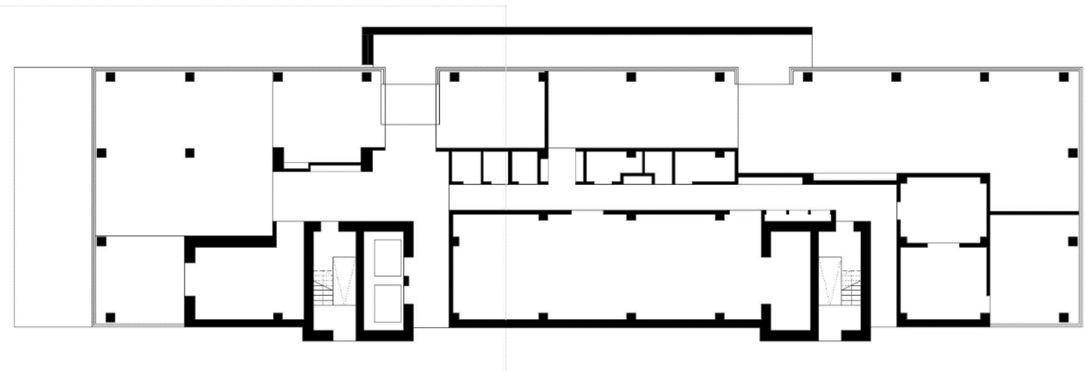
Architects: Acton Ostry Architects Inc
Location: Vancouver, Canada
Area: 15,100m^2
Completion date: 2017
Function: Student housing for University of British Columbia

5.1.1 General Information

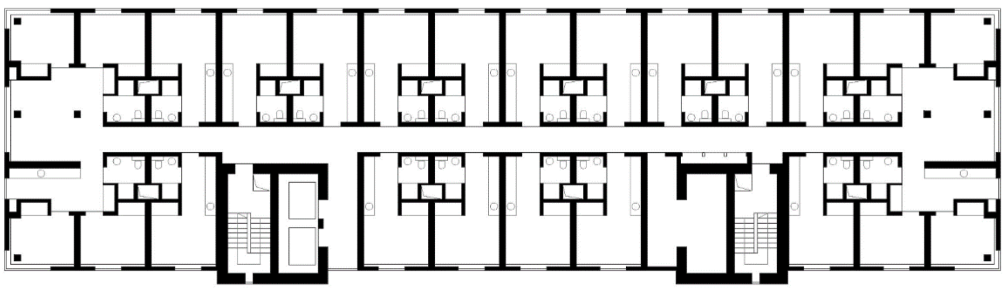
This 18-storey building is app. 53m height and at the time of its completion was the highest timber residential building in the world. It was built as a part of a pilot program - Canadian Wood Council's Tall Wood Initiative which aimed to prove that the timber structures are as viable option as the traditional structural materials for the mid and high-rise buildings. It consist of dwelling units like: studios and 4 bed apartments. The facilities for the student community is located on the ground floor and on the top floor. The footprint of the building is approximately 15m x 56m. Due to the high level of prefabrication it was built in 18 months.

5.1.2 Structural system analysis

One of the most characteristic feature of the Brock Commons structure is the utilization of the CLT flooring panels with integrated two way spanning capability in order to get rid of the need for the load bearing beams which resulted in significant reduction of the weight of the structure and the structural depth of the building. The structural grid of columns have been optimized in order to maximize the size of the flooring panels which resulted in minimal amount of plates used per floor and to adjust to the architectural layout of the building.*(CAR24)* The CLT floors are supported by GLT and PSL columns that are subjected to the gravity load and transfer it to the lower concrete structure. In order to prevent the floor from cracking the vertical loads are directly transferred from column to column by the steel HSS connector buried inside the floor plate. The lateral loads however, are transferred through the CLT floor by steel drag straps and ledge angles that are further transferred to the structural cast-in-place reinforced concrete cores. The floor heights of the mass timber levels is set to be 2,81m while the ground floor made out of concrete is 5m high. *(CAR22)*

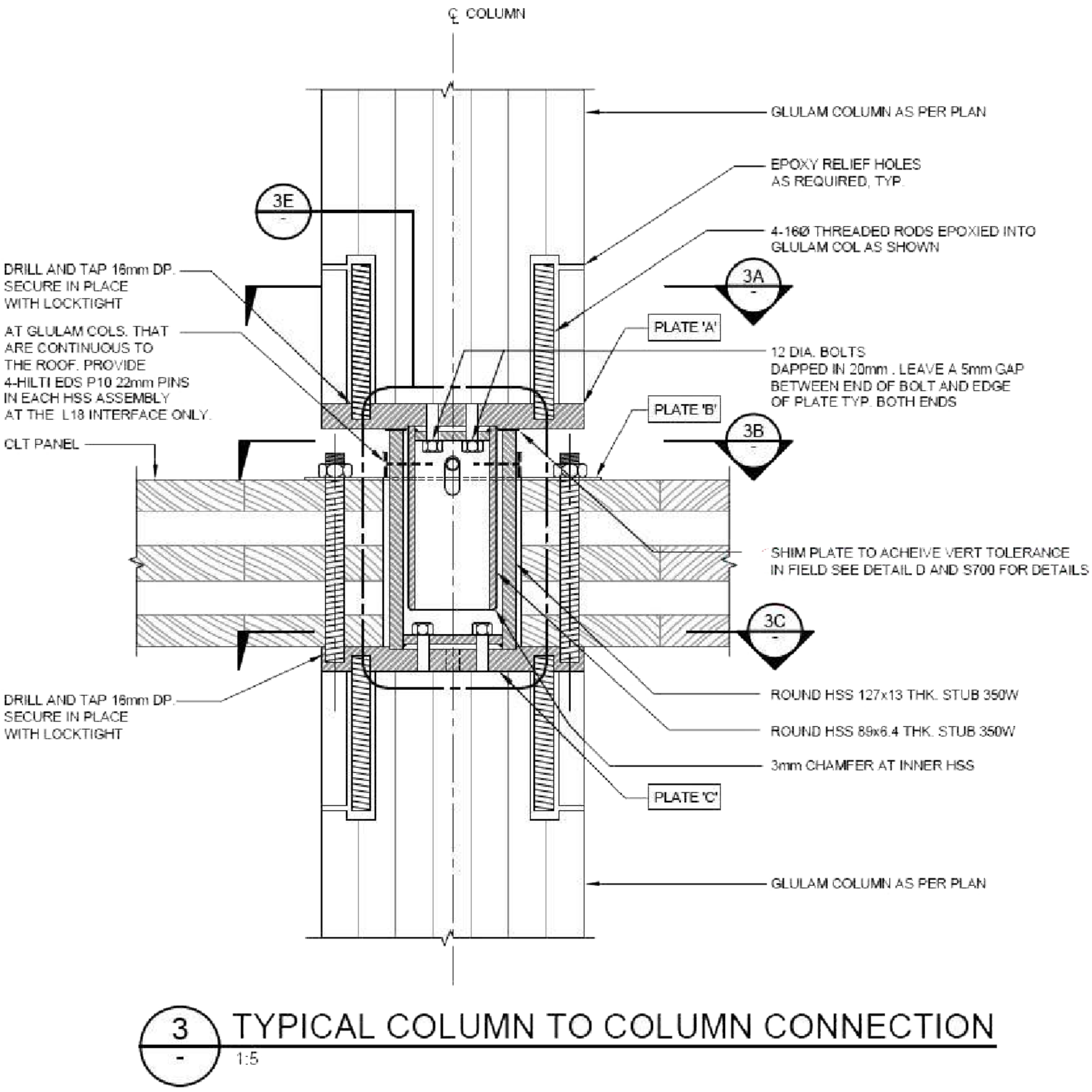


Ground Floor Fig. 1.5



Typical Floor Fig. 1.6

Although the structure is very systematic it does not consist of modular elements, instead it utilizes 2d floor plates and prefabricated facade panels. *(CAR4)* The floors are covered with thin concrete topping in order to enhance the acoustics properties and to make the floors more fire resistant. The bottom side of the floor plates were encapsulated by three layers of gypsum boards. On the other hand, the envelope consists of prefabricated facade panels. They consist of steel-stud frames, fiberglass gypsum sheathing, stone-wool thermal insulation and the exterior wood-fiber laminate panels. The interior finish and the vapor barrier were added later when the envelope was already enclosed. The facade panels were rigged on I-beam spreader bars attached to the lower floors while the steel L-angle were used for actual bolting it to the upper floor. In result the façade panel is hanging from the upper floor on the steel L-angle while the bottom part is secured by the interlocked I-beam.



HSS Steel connector Fig.1.7

Due to the conservative fire safety regulations in British Columbia the mass timber structure has been encapsulated with three layers of Type X gypsum boards which resulted in thinner cross-section of mass timber components since there was no need to accommodate for charring aspect. The exception is on the top floor where ten Glulam columns are fully exposed. The encapsulation of the timber structure with addition of the sprinkler system should result in self-extinguishing of the fire in just 90 minutes. Additionally, fire standpipes were installed in the concrete cores.

5.1.3 Versatility & Convertibility Grading

The building possesses multiple characteristics that are aligned with the versatility properties. The structural grid creates a regular planning grid capabilities with a span of 2.85m x 4m. Although the grid is not it particularly large it creates a coherent planning area for perpendicular partition walls that create systematic rectangular rooms. *(CAR33)* Due to the regular planning grid of the building it is easy to change the spatial layout of each floor by removing or adding new partitions. *(CAR24)* The rectangular shape and the inherent low depth of the building creates great natural light conditions that enhances the convertibility properties since the spatial layout is not dictated by the lighting conditions. *(CAR39*) Although it is rather easy to change the layout of the building the function is rather homogenous though it possesses some minor multifunctional areas like the ground floor with irregular spatial layout and the top floor which is turned into coworking area.*(CAR43*) However, the wide distribution of installation shafts can be problematic if the users would want to change the spatial configurations since they are rather close to the exterior walls. The building structure is based on Glulam columns and flat CLT panels while the ground floor is made predominantly of concrete which changes the size of the structural grid.*(CAR4)* The exact measurements are not available however, it is safe to assume that the structural grid of concrete columns is roughly 1.5 times the span of the timber based grid which enhances the spatial openness capabilities where its mostly needed – in the multifunctional area of the building.(*CAR22/CAR47)*

Structural grid size shift between different functions Fig. 1.8

The wide circulation of the entire building is provided by two separate structural concrete cores equipped with staircases and elevators. *(DT45/CAR49)* This solution provides increased stiffness to the structure which compensates for highly flexible and lighter timber based part and creates multiple communication routes for its users.*(CAR57)*

SPATIAL ADAPTABILITY	VERSATILITY									CONVERTIBLITY				
	CAR33	CAR24	CAR50	CAR49	CAR21	CAR4	CAR47	CAR29	CAR43	CAR22	CAR42	CAR57	CAR39	
CASE 1	1	1	1	-	-	0,5	0,5	-	-	0,5	0,5	-	1	6,0
CASE 2														
CASE 3														

Points admitted to Case 1 Table 1.2

Puukuokka Housing Block Fig. 1.9

5.2. Case 2 Puukuokka Housing Block

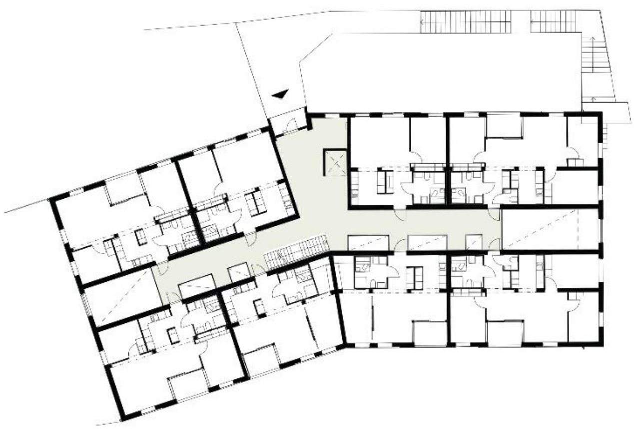
Architects: OOPEAA
Location: Jyväskylä, Finland
Area: 10 000 m^2
Completion date: 2018
Function: Residential

5.2.1 General Information

This apartment complex consists of three blocks of flats made predominantly from mass timber buildings which consist of 184 apartments in total. It was the highest timber based apartment building and also the first mass timber high-rise in Finland. The first building was finished in 2015 while the last one was finished in 2018. It is a pilot project that explored a mass timber modular concept for single-family dwelling. It is also a pilot project in terms of ownership since it provides a special rental program that allows lower income individuals to buy an apartment for 7% of the total price and the rest is being paid in the state guaranteed installments which after 20 years ends up with full ownership of said apartment. The project has been tremendously popular among the inhabitants and architectural professionals alike due to its architectural quality and innovative concept merged with sustainable materiality. The project was designed in close collaboration with the Jyväskylä City Planning Department in order to promote environment-friendly affordable housing.

5.2.2 Structural system analysis

The loadbearing system consists of CLT modules and frames with addition of reinforced concrete cast in place ground floor and basement. All the mass timber structural elements like facade plates or room modules have been prefabricated which resulted not only in quick assembly but also unified high quality of the entire building.*(CAR33)* Such elements have been assembled in controlled indoor conditions and then transported on site and plugged into the structure. Thanks to that the weather is no longer a factor for the construction process which also sped up the whole operation. Only the concrete basement, ground floor and the connecting hallway has been constructed on site. The modular structure was developed by the manufacturer Stora Enso which used only CLT for the load bearing elements.

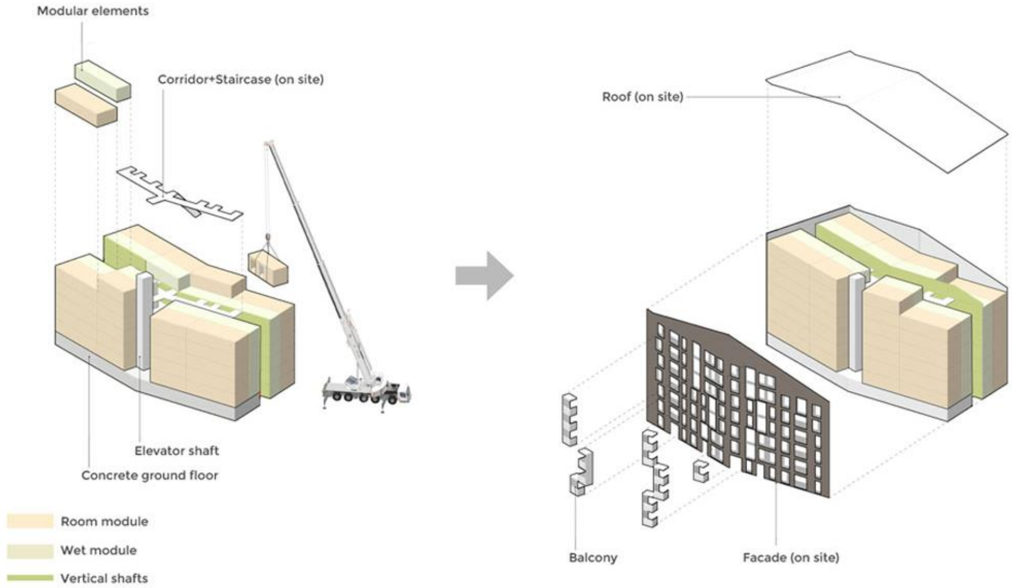


Puukuokka Housing Block – Floor plan Fig. 1.10

Due to the modular nature of the building and the insulation properties of mass wood, the temperature of each unit can be controlled independently while the spacious hallway with additional skylight can still be treated as semi-warm space without any additional heating systems. The structural CLT frame is also used as the vapor barrier which provides better stability in case of moisture attack. The fire regulations in Finland were quite conservative but they were changed in 2010 due to the rapid popularization of CLT material and its inherit fire resistant properties. Therefore the construction of such a 8-storey building was possible as long as the main CLT frame was coated and the automated sprinkler system was in place. The main founder of OOPEAA claims that following the new standard for fire safety the average mass timber apartment is up to 50 times more safe than the concrete counterpart.

5.2.3 Versatility & Convertibility Grading

The characteristic modular structure of the building creates certain spatial and functional situations that are on the spectrum of spatial adaptability. The use of the room module indicated the standardized dimensions throughout the project and unified planning grid, framed by the dimensions of a single module. *(CAR33)* On the other hand, the inherit rigidness of a module creates very limited options to change the layout of the building or alter its function, since the room module itself has been designed in such a way that all the separation walls are loadbearing and there is no option to tear them down without hindering the structure. Moreover, the facade is not a part of the modular structure but its installed separately which makes impossible to interchange the room modules throughout the lifecycle of the building.*(CAR24)* The layout of the building is subjected to the dimensions of the modules which were placed in such a way to provide maximum amount of sunlight for the dwelling units. The shared hallway is well lit and possesses a spacious feel due to the extensive amount of windows and larger than usual dimensions however, due to the sheer size of the building such space cannot be used for anything else than transportation. *(CAR57,CAR22,CAR50)*



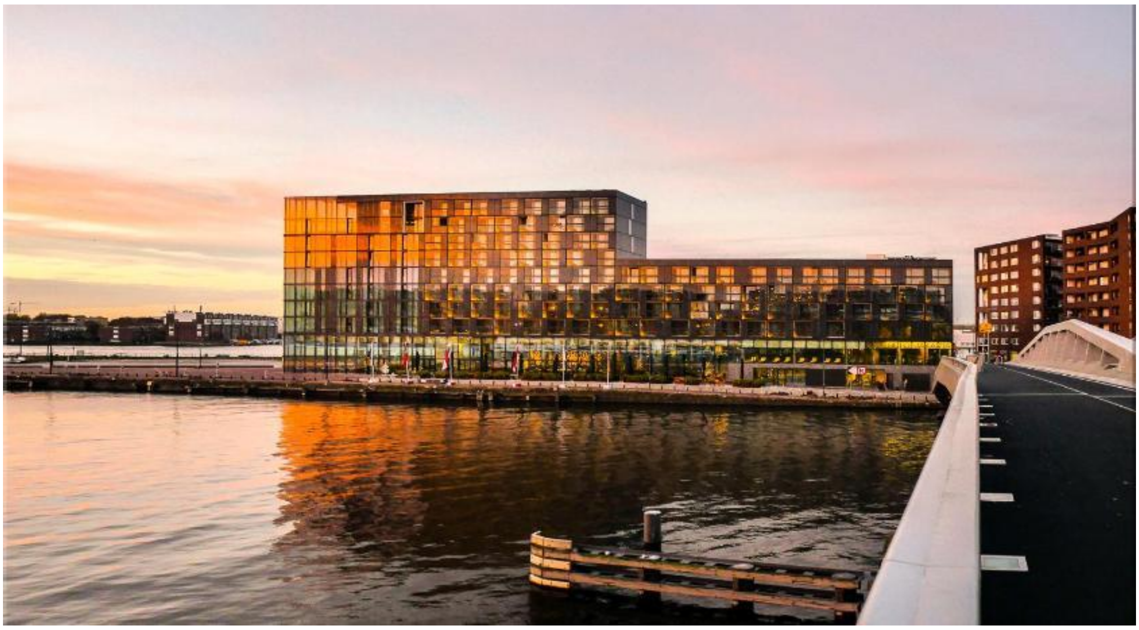
Assembly diagram Fig. 1.11

The flats consist of two modules each, one on the outer part of the building consists of living unit and the second one, that provides utilities to the apartment, that is allocated in the interior part of the building.*(CAR4)* The installations are located into the wall structure from the hallway side of the building, which results in easy access in case of maintenance or repair. Although the function seems to be homogeneous and the layout of the building does not allow for easy convertibility of a building, the adaptable part of the project resides in the fact that the vast majority of the structure is fully prefabricated which means fewer joints, precise construction and less materials were used which in the end means that the building can be relatively easily refurbished or completely dismantled if needed.*(CAR33)*

SPATIAL ADAPTABILITY

	VERSATILITY									CONVERTIBLITY				
	CAR33	CAR24	CAR50	CAR49	CAR21	CAR4	CAR47	CAR29	CAR43	CAR22	CAR42	CAR57	CAR39	
CASE 1	1	1	1	-	-	0,5	0,5	-	-	0,5	0,5	-	1	6,0
CASE 2	1	-	1	-	0,5	1	0,5	-	-	0,5	1	-	1	6,5
CASE 3														

Points admitted to Case 2 Table 1.2



Jakarta Hotel Fig. 1.12

5.3. Case 3 – Jakarta Hotel

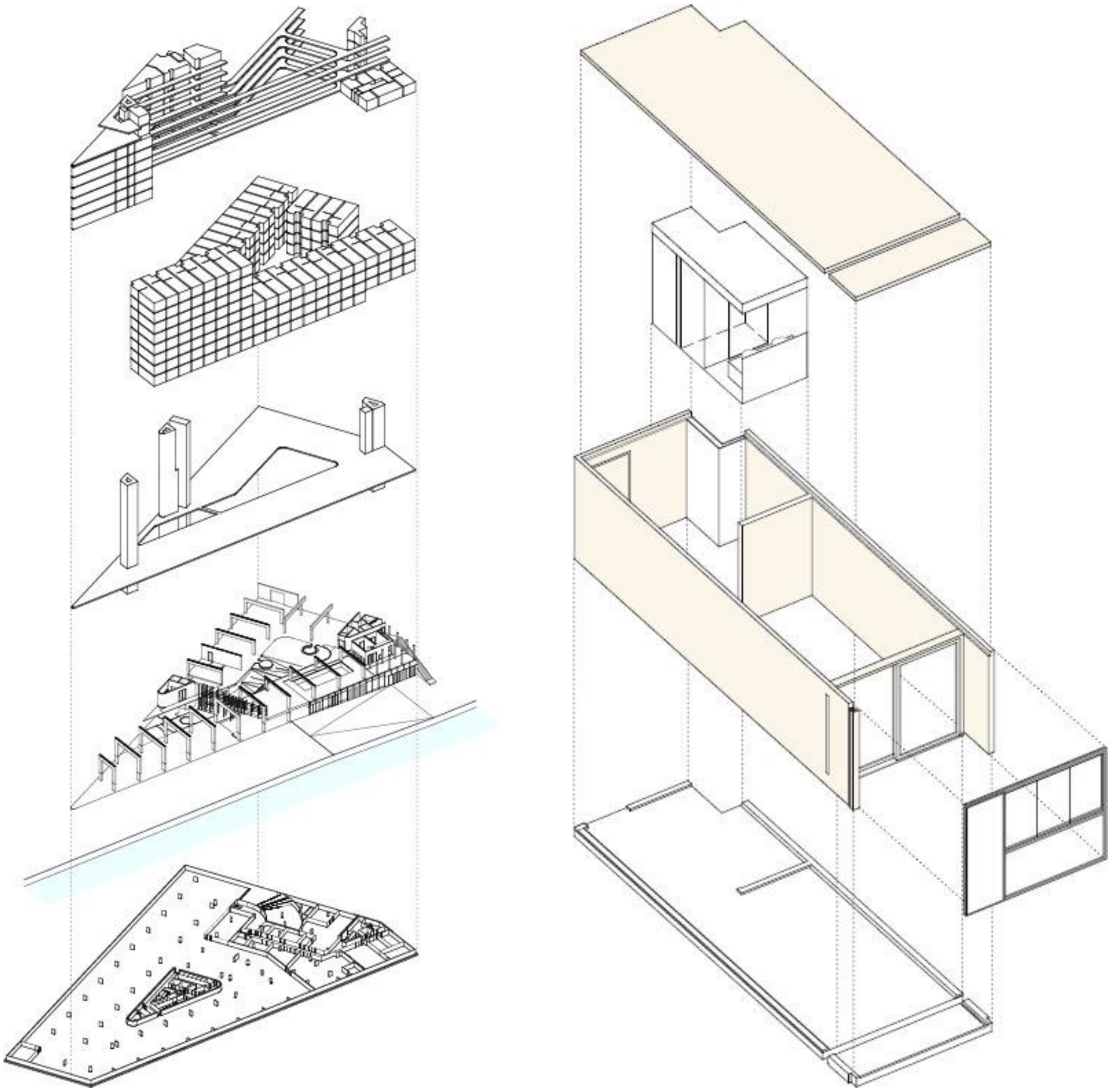
Architects: SeARCH
Location: Amsterdam, Netherlands
Area: 16 500 m^2
Completion date: 2018
Function: hotel

5.3.1 General Information

The building was designed in order to create a prominent end point of the Java Island and to incorporate public functions within the design of a hotel building while promoting the sustainability of built environment. The project achieved a BREEAM Excellent certification being the most sustainable hotel in the Netherlands. The glazed exterior with nearly transparent public ground floor does not signify the modular mass timber structure. The building provides 200 hotel rooms, public atrium with a sub-tropical garden, café and sky-bar. The height of the building reaches up to 30 m.

5.3.2 Structural system analysis

The structure of the building consists of mass timber room modules that are braced with mass timber supporting structure and the concrete skeleton which acts as a base for the mass timber elements which stiffens the structure.*(CAR33)* All vertical loads are transferred to the reinforced concrete foundations through the walls of self-supporting modules. The horizontal loads are diverted to the three concrete stairwells with elevator shafts. The prefabricated modules are



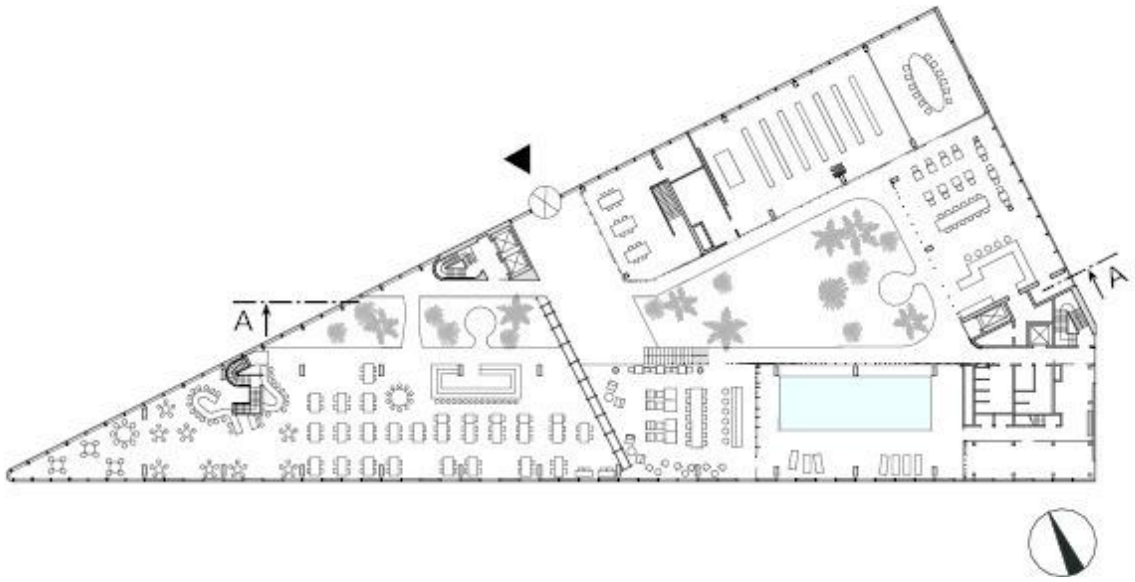
Assembly diagram Fig. 1.13

surrounding the central atrium that serves not only as a public space/garden but also as a temperature regulatory area. The glazed roof is covered by the PV panels that also serves as a shading system for the garden. The atrium is enclosed by the roof that is supported by CLT trusses that were placed directly on top of the room modules. However, the girder has been additionally spanned in the longitudinal direction. *(CAR50,CAR47).* All room modules are completely prefabricated with concrete screed on the floor and furnishing inside the room. They were prefabricated at the Ursem Modulaire Bouwsystemen factory where every two hours a new module was created, fitted with all the necessary installations ready to be stacked on site. The loadbearing walls of room modules were made from CLT with a five-sheet layer which allowed for stacking of modules that reached up to 8 layers making it the highest modular mass timber structure in the Netherlands.

Although the number of room modules might seem extensive the entire erecting process took only four weeks due to the high level of prefabrication of the building. The choice of concrete screed for the floors of modules was justified by the thinner cross-section of each floor which resulted in bigger windows and more densely packed room modules that resulted in placing nearly 200 of them in such a small and narrow site. The concrete improved the acoustic insulation that was crucial for a hotel design. Furthermore the acoustics insulation was also improved by a 4cm thick rock wool layer in between the room modules. Concrete floor screed improved the fire resistance however, it was not the main goal since the automated sprinkler system was enough to accommodate for fire safety in this building.

5.3.3 Versatility & Convertibility Grading

The spacious open plan of the ground floor creates various opportunities for versatile changes of function. The structure of the ground floor based on columns and structural cores provides framework for various spatial configurations that can be implemented during the lifecycle of a building *(CAR24)* At the heart of the building is a big atrium with a sub-tropical garden that acts as a main communication channel that leads people either to the other public areas and function or to the hotel rooms that are surrounding the atrium. *(CAR50,CAR22)* The open passage from the public atrium to the outside of the building creates a sort of a semi-closed public square that can host multiple activities throughout the day. *(CAR43,CAR29)*



Ground Floor Fig. 1.14

The structural cores located on the outer rim of the building provide multiple access points to the internal function which creates an opportunity to divide the building into various layouts of functionality.*(CAR57,CAR49)* However, the layout of the higher floors is changed significantly due to the different typology of the structure. The layout is based on modules that utilize loadbearing walls instead of columns, which makes the change of functional layout nearly impossible due to the inherent rigidness of prefabricated modules. On the other hand, the modularity of the building makes the structural grid rather regular with a few exceptions *(CAR33)* AS such the most adaptable area of a building is clearly the ground floor due to its open plan design and the dominating atrium that is connected to the exterior, while providing vertical connection to the upper floors.

SPATIAL ADAPTABILITY

	VERSATILITY									CONVERTIBLITY				
	CAR33	CAR24	CAR50	CAR49	CAR21	CAR4	CAR47	CAR29	CAR43	CAR22	CAR42	CAR57	CAR39	
CASE 1	1	1	1	-	-	0,5	0,5	-	-	0,5	0,5	-	1	6,0
CASE 2	1	-	1	-	0,5	1	0,5	-	-	0,5	1	-	1	6,5
CASE 3	1	1	1	1	0,5	0,5	1	0,5	1	0,5	-	1	1	10

Points admitted to Case 3 Table 1.3

VI. Conclusion

Although the existing systems of adaptable design are being tested on numerous new structures there are no clear indications for spatial adaptability, rather a systematic solution to the general adaptable characteristics where components can be relatively easily refitted or changed. However, those concepts as such, do not provide a clear definition of what the spatial strategy should be to achieve adaptability. What is more, the actual number for such concepts is rather untold since numerous scholars created their own updates to those two main concepts mentioned above which does not provide a clear answer of what can be done in this matter. Besides, the take on spatial adaptability is already confusing since there is no clear definition on what such concept should accommodate. What is lacking is the clear indication on what adaptable architecture should accommodate and how to evaluate such adaptability in a built environment. This problem has been specifically addressed in the book *Adaptable architecture : theory and practice* Schmidt III R. Austin S. (2016) and therefore it served as a backbone of this research that attempts to provide quantifiable results on this subject. The research paper provides an insight into the ambiguity of the adaptable architecture concept and showcases different strategies to achieve it. The evaluation results can be used to approximate which combination of timber based modules can be used in order to design a mid/high-rise timber based multifunctional building with spatial adaptability capabilities.

	SPATIAL ADAPTABILITY													
	VERSATILITY									CONVERTIBLITY				
	CAR33	CAR24	CAR50	CAR49	CAR21	CAR4	CAR47	CAR29	CAR43	CAR22	CAR42	CAR57	CAR39	
CASE 1	1	1	1	-	-	0,5	0,5	-	-	0,5	0,5	-	1	6,0
CASE 2	1	-	1	-	0,5	1	0,5	-	-	0,5	1	-	1	6,5
CASE 3	1	1	1	1	0,5	0,5	1	0,5	1	0,5	-	1	1	10

Table 1.4 Case study evaluated

Although the case study examples were especially chosen to have spatial adaptability properties embedded into their design it is clear that the sheer materiality is not enough to provide sufficient degree of spatial adaptability. It appears that the biggest limitation in terms of spatial adaptability is the predominant use of the room modules that utilize loadbearing walls as a main structure, due to the no real possibilities to change the layout of the building. However, the inherent modularity allows for quick dismantling and rebuilding it in some other manner, re-using the concrete plinth and possibly some of the modules in order to convert the building for another function. The materiality of mass-timber allows for further reuse of materials due to the enhanced weather resistance and slower deterioration of structural integrity than traditional materials and great recycling properties. The case study shows that it is also important to design multiple spaces with different structural typology in order to enhance the adaptability of a structure. The Case 3 shows best that even with predominant rigid structure of the modular upper floors the ground floor with an open plan and well though transportation schematics can be easily refitted with various functions and layouts which was awarded with the highest spatial adaptability score in this research. Case 2 on the other hand, having a similarly predominant modular structure does not possess the same adaptable properties due to the ground floor that cannot accommodate for any further function, while the shared hallway is spacious but not spacious enough to accommodate any functional adaptations for the future use. Furthermore, the unified envelope is not designed for a quick refit nor dismantle and the modular properties are somewhat lost at least in terms of the envelope change, while the Case 3 utilizes room modules with already fitted facade elements which makes it easier to refit a single façade plate if needed. It also allows for partial conversion of the building which can be emphasized by partial change of the modular façade. The Case 1 on the other hand does not use room modules but it utilizes a highly repeatable structural system that consists of a unified column system with 2d elements like prefabricated façade panels and floor plates. Thanks to that the layout of each floor can easily transition to another function, due to the skeleton-like structure and nearly no loadbearing walls and two cores that create alternative ways of transportation. This particular adaptability feature that allows for functional layout of each floor is something that is clearly missing in other cases due to the column based structure instead of hybrid frame and room modules which creates additional restraints for adaptability. The combination of the room modules and the column based system could be the solution that this research is attempting to look for. The room module utilizes loadbearing columns and infill walls that can be separated from the structure and refitted or dismantled inside of the building in order to accommodate for various functional layouts on each floor.

However, this conclusion comes more from the case study itself using spatial adaptability characteristics as criteria than the quantifiable results of the evaluation grid that has been used here. The problem with the grading system is in fact the sheer property of spatial adaptability subject where no building can accommodate for every possible change of layout or function and each building is designed for a precise task imposed by the client, budget, local building code etc. Furthermore the simplified grading system proposed here is grading specific characteristics but it does not show the degree of that such characteristic applies to the entire building. In other words, the most versatile space in each of the buildings is the ground floor, without it the rigidity of modular loadbearing walls does not allow for much spatial adaptability anyway. The experiment however, showcases general rules and its materiality for further research and development. Further reflection can be found in **[Appendix 1]**

VII. References

Literature:

1. Wallance D.(2021), *The Future of Modular Architecture*, Routledge, ISBN 9780367467227

2. Farokhi Firouzi H.(2019), *A Review on Flexibility in Architectural Design*, Department of Architecture, Faculty of Art & Architecture, Islamic Azad University, ISSN 2228-9860

3. Kaufmann H. Krotsch S. Winter S. (2018), *Manual of Multi-Storey Timber Construction*, Detail Business Information Gmbh Munich, ISBN: 9783955533946

4. Staib G. Dörrhöfer A. and Rosenthal, M.(2008), *Components and Systems: Modular Construction–Design, Structure, New Technologies*, Walter de Gruyter. ISBN: 9783034615662

5. Smith Wiley R. (2010),*Prefab Architecture A Guide to Modular Design and Construction*, ISBN 9780470275610

6. Habraken N.J. (2008), *Design for Flexibility: Building Research and Information*. ISSN 0961 3218

8. Askar R, Bragança L, Gervásio H.(2021) *Adaptability of Buildings: A Critical Review on the Concept Evolution*. Applied Sciences.; 11(10):4483. https://doi.org/10.3390/app11104483

9. 2021, *GSR for building and construction*, United Nations Environment Program

10. 2011, *American Heritage Dictionary of the English Language*, Houghton Mifflin Harcourt

11. Kronenburg R. (2007) *Flexible: Architecture that Responds to Change*. Laurence King Publishers

12. Schmidt III R. Austin S. (2016), *Adaptable architecture : theory and practice*, New York : Routledge, ISBN 9781315722931

13. Russell P. Moffatt S. (2001), *Adaptability of Buildings*, IEA Annex 31 Energy-Related Environmental Impact of Buildings

14. *Buildings that last : design for adaptability, deconstruction, and reuse*
Paula Melton of BuildingGreen Inc.

15. Isaac, S. Bock T. Stoliar Y.(2016), *A Methodology for the Optimal Modularization of Building Design*. Autom. Constr. 65, p. 116–124.

16. T*all Wood Buildings* by M. Green and Jim Taggart(2017) (ISBN PDF 978-3-0356-0476-4)

Illustration:

FIG. 1.1 Schmidt III R.;Austing S.(2016)
FIG. 1.2 Schmidt III R.;Austing S.(2016)
FIG. 1.3 Schmidt III R.;Austing S.(2016)
FIG. 1.4 https://www.naturallywood.com/brock-commons/
FIG. 1.5 https://www.naturallywood.com/brock-commons/
FIG. 1.6 https://www.naturallywood.com/brock-commons/
FIG. 1.7 https://www.archdaily.com/tallwood-house/
FIG. 1.8 https://www.archdaily.com/tallwood-house/
FIG 1.9 https://www.archdaily.com/614915/puukuokka-housing-block-oopeaa
FIG 1.10 https://www.archdaily.com/614915/puukuokka-housing-block-oopeaa
FIG 1.11 https://puuinfo.fi/arkkitehtuuri/block-of-flats/puukuokka-housing-block/
FIG 1.12 https://hoteljakarta.com/sustainably-built/building/
FIG 1.13 https://www.search.nl/works/hotel-jakarta/
FIG 1.14 https://www.search.nl/works/hotel-jakarta/

APPENDIX 1 - REFLECTION PAPER

1. What is the relation between your graduation project topic, your master track (Ar, Ur, BT, LA, MBE), and your master programme (MSc AUBS)?

The project topic is focused on the practical means to create an adaptable building that would utilize sustainable structural materials. The theory is based on the Open Building concept and it aspires to be a part of “1 milion homes” studio topic as well since it adds on the Campus housing capabilities.

2. How did your research influence your design/recommendations and how did the design/recommendations influence your research?

Initially before the research phase even started my personal view on the subject of adaptability in architecture was mainly based on a impression that there are various adaptable structural systems and it should be rather easy to find out more about them and try to innovate in terms of spatial adaptability. However, that impression has quickly vanished as I realized not only there are no standardized structural systems dedicated to the adaptable architecture but also the adaptability aspect of it is a very ambiguous but broad topic at the same time. Essentially it appeared that there are some standard strategies in order to achieve some kind of adaptability but every aspect of it is purely custom. Having that said, there are many 3d module based structural systems on the market but all of them are specifically designed to be simply stacked on top of each other that leaves not much room for architectural pursue for innovation. This realization made me change my initial plans for the design phase. Instead of looking for a perfect technical solution that would influence my entire project I tried to look for a solution by using multiple different structural systems and utilize them in a new fashion in order to enhance the spatial adaptability properties.

3. How do you assess the value of your way of working (your approach, your used methods, used methodology)?

Although the topic of adaptable architecture seems to be pretty popular around the building industry, there is no clear consensus on what such architecture should or shouldn’t entain. Various scholars and practitioners created their own visions of adaptable architecture, often intertwining each others concepts but the topic itself remains blurry. My approach addresses this ambiguity, although it doesn’t provide a clear answer to the problem it may shed a new light into the issue of spatial adaptability by comparing and evaluating design characteristics of adaptable architecture in timber high-rise buildings.

4. How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

The inherit value behind modularization of a building is its capability to change or adapt to the new situation. The project is designed in such a way that its function can be altered in the future providing new possibilities for the local community. The innovative way of merging the modularity of dwelling units with the open mega-core structure provides better environment for the co-living situation of its inhabitants. The resulting verticality of the housing units can be an interesting alternative for the future conversions from the student housing to the private apartments or offices, depending on the current demand.

5. How do you assess the value of the transferability of your project results?

The final design project can potentially become a pilot project for other Campus related buildings regarding timber-based structures and their incremented spatial flexibility. The emphasis on adaptability can be a vital point of discussion about the Campus’s future and its limited land available for new construction. The experimental approach to the use of timber based modular system incorporated into a high-rise can influence the strategies of the sustainable future of timber high-rise structures.

6. How did your research conclusion contributed to the design phase?

Due to the better understanding of the subject of adaptability I realized that not every adaptability strategy is viable for implementation in one project. The theme of adaptability can reach way further then the removable or moving walls and dynamic facade. My approach to the project design focused more on the enablers of the adaptable qualities rather then forcing a change on its users by developing elaborated systems that might be never used as intended. Providing possible scenarios for the same space that can be utilized in the future without creating an artificial demand for a change.

7. What is the most specific aspect of your design project that could potentially influence your research paper in hindsight?

In my project I focused more on the unorthodox use of timber based room modules that can influence the architectural value and introduce new co-living qualities to the building. It is based on a premise that the entire building can be boiled down into a few singular elements that after certain elaborate arrangement it can create an intriguing and functional building. The research could be more focused on the specific subject of room modules and how to utilize them in new ways.

VIII. APPENDIX 2 – DESING TACTICS & CHARACTERISTICS

#	Tactic Name	Related Characteristic(s)	#	Tactic Name	Related Characteristic(s)
DT1	Reversible connection	CAR1, CAR3, CAR6, CAR8, CAR19	DT15	Adjustable fixtures	CAR6
DT2	Intermediate component	CAR1	DT16	Primary/temporary functions	CAR7, CAR45, CAR49
DT3	Loose furniture	CAR2	DT17	Cheap materials	CAR8
DT4	Movable partitions	CAR2	DT18	Existing/temporary space	CAR8
DT5	Simple & minimum finishes	CAR3, CARI9	DT19	General surplus capacity	CAR9, CARI4
DT6	Access space	CAR3	DT20	Specific surplus capacity	CAR9, CARI4
DT7	Framed structure	CAR4	DT21	Weatherable materials	CAR10, CAR56
DT8	Spatial separation	CAR4	DT22	Low maintenance	CAR10
DT9	Layered exterior	CAR4	DT23	Knockable	CAR10
DT10	Wing control (chunk of building)	CAR5, CAR46, CAR48	DT24	Mature building technology	CAR11, CAR19
DT11	Floor control (horizontal slices)	CAR5, CAR46, CAR48	DT25	Practice-based	CAR11
DT12	Tenant control (spatially)	CAR5, CAR46, CAR48	DT26	Efficient devices (reduce heat gain)	CAR12

#	Tactic Name	Related Characteristic(s)	#	Tactic Name	Related Characteristic(s)
DT13	Adjustable furniture	CAR6	DT27	Service monitoring	CAR12
DT14	Adjustable partition	CAR6, CAR24	DT28	Local source (water, energy)	CAR12
DT29	Hand made traits	CAR13,	DT67	Spatial adjacencies	CAR29
DT30	Industrialised solution	CAR13, CAR18	DT68	Spatial transitions	CM.29
DT31	Natural materials	CAR15	DT69	Vertical organisation of uses	CAR29
DT32	Local materials	CAR15, CAR58	DT70	Opens to outside (9b)	CAR29
DT33	Reclaimed materials	CAR15	DT71	Functional qualities	CAR30
DT34	Standard product	CAR15, CAR16	DT72	Fixed vs. flexible space	CAR30
DT35	Standardised solution	CAR16, CAR19	DT73	Central location	CAR31
DT36	Standard grid	CAR17	DT74	Close proximity	CAR31
DT37	Standard distance from	CAR17	DT75	Orthogonal shapes	CAR32
DT38	Prefabricated solution	CAR18	DT76	Multiple rectangles	CAR32
DT39	Box-shaped	CAR19	DT77	Rectangle	CAR32
DT40	Wide span	CAR20,	DT78	Planning grid	CAR33
DT41	Thin columns	CAR20	DT79	Structural grid	CAR33
DT42	Extra space (not in the brief)	CAR21	DT80	Box-shaped	CAR34
DT43	Storage space	CAR21	DT81	Vertical walls	CAR34
DT44	Exterior space	CAR21	DT82	Cross ventilation	CAR35
DT45	Wide circulation (10a)	CAR21, CAR22, CAR43, CAR50	DT83	Stack ventilation	CAR35
DT46	Additional circulation	CAR21, CAR50	DT84	Mechanical ventilation	CAR35
DT47	Undefined space	CAR21, CAR43, CAR47	DT85	Minimum distance	CAR36

Table 1. Design tactics and corresponding characteristics. R.Schmidt III, S.Austin(2016)

#	Tactic Name	Related Characteristic(s)	#	Tactic Name	Related Characteristic(s)
DT47	Undefined space	CAR21, CAR43, CAR47	DT85	Minimum distance	CAR36
DT48	Tall floor heights	CAR22	DT86	Control heat gain	CAR37
DT49	Enlarged ground floor	CAR22	DT87	Thermal mass	CAR37
DT50	Enlarged spatial area	CAR22	DT88	Natural cooung	CAR37
DT51	Universal image (familiar)	CAR23, CAR54	DT89	Maximise natural ventilation	CAR38
DT52	Standard room sizes	CAR23	DT90	Reflect use patterns	CAR38
DT53	Standard room locations	CAR23	DT91	Maximise north/south exposure	CAR38
DT54	Standardised specificity (scale, equipment)	CAR23, CAR43	DT92	Indirect light (reilected transferred)	CAR39
DT55	Add/take down a wall	CAR24	DT93	Direct light (openings, permeable skin)	CAR39
DT56	Create/remove opening	CAR24, CAR26	DT94	Shallow plan depth	CAR39
DT57	Number/location of core	CAR24	DT95	Expand into roof	CAR40
DT58	Spatial coordination	CAR25	DT96	Expand onto roof	CAR40
DT59	Grid coordination	CAR25	DT97	Expand floor plate	CAR40
DT60	Create link	CAR26	DT98	Underground	CAR40
DT61	Market standard	CAR27	DT99	Neighbouring site	CAR40
DT62	User defined	CAR27	DT100	Existing site	CAR40
DT63	Informal/ formal (variety)	CMR28	DT101	Shell & core (trvo stage construction)	CAR41
DT64	Room sizes (variety)	CAR28, CAR46	DT102	Bare bones (genoric infrastrcuture)	CAR41
DT65	Interior/exterior (variety)	CAR28	DT103	Empty space (stuff level)	CAR42
DT66	Finishes/furnishings (variety)	CAR28, CAR43	DT104	Custom finishes	CAR42
DT105	Underused space	CAR43	DT121	Colour	CAR52
DT106	Open space	CAR43, CAR5I, CAR53	DT122	Art	CAR52
DT107	Use zones	CAR44	DT123	'Human' finishes	CAR53
DT108	Mixed uses (17a)	CAR44	DT124	Striking image (unique)	CAR54
DT109	Use differentiation	CAR45	DT125	Unresolved geometries	CAR55
DT110	Variety of contract types	CAR46	DT126	Nooks & crannies	CAR55
DT111	Common space	CAR47	DT127	Historic narrative (design concept)	CAR56
DT112	Hot-desking	CAR47	DT128	Transportation links	CAR57
DT113	Shared identity	CAR47	DT129	Supplementary uses	CAR57
DT114	Individual space(s)	CAR48	DT130	Topographic	CAR58
DT115	Multiple tenants	CAR49	DT131	Relational	CAR58
DT116	Secondary entrance	CAR49	DT132	Linked circulation points	CAR59
DT117	Direct links	CAR50	DT133	Direct access	CAR59
DT118	Prominent design feature	CAR50	DT134	Mixed demographics	CAR60
DT119	Views (outward looking)	CAR51	DT135	Social space	CAR60
DT120	Transparent materials	CAR51			

Table 1. Design tactics and corresponding characteristics. R.Schmidt III, S.Austin(2016)

PHYSICAL	
DSI: MODULARITY	
CARI	Reversible
CAR2	Movable stuff
CAR3	Component accessibility
CAR4	Functional separation
DS2: DESIGN 'IN' TIME	
CAR5	Service zones
CAR6	Configurable stuff
CAR7	Multi-functional components
CAR8	Not precious
CAR9	'Extra' components
DS3: LONG LIFE	
CAR10	Durability
CAR11	Mature component
CAR12	Efficient services
CAR13	Good craftmenship
CAR14	Overdesign capacity
CAR15	Readily available materials
DS4: SIMPLICITY & LEGIBILITY	
CAR16	Standardised components
CAR17	Standard component locations
CAR18	Off-site construction
CAR19	Simple construction method

SCALES	
DS11: AESTHETICS	
CAR52	Attitude & character
CAR53	Spatial quality
CAR54	Building image
CAR55	Quirkiness
CAR56	Time interwoven
DS12: MULTIPLE SCALES	
CAR57	Good location
CAR58	Contextual
CAR59	Circulation (neighbourhood scale)
CAR60	A communal place

SPATIAL	
DS5: LOOSE FIT	
CAR20	Open space
CAR21	Support space
CAR22	Oversize space
DS6: SPATIAL PLANNING	
CAR23	Typology pattern
CAR24	Joinable/divisble space
CAR25	Modular coordination
CAR26	Connect buildings
CAR27	Standard room size(s)
CAR28	Spatial variety
CAR29	Spatial ambiguity
CAR30	Spatial zones
CAR31	Spatial proximity
CAR32	Simple plan
CAR33	Standard grid
CAR34	Simple form
DS7: PASSIVE TECHNIQUES	
CAR35	Multiple ventilation strategies
CAR36	Shallow plan depth
CAR37	Passive climate control
CAR38	Building orientation
CAR39	Good daylighting
DS8: UNFINISHED DESIGN	
CAR40	Space to grow into
CAR41	Phased
CAR42	User customisation
DS9: MAXIMISE BUILDING USE	
CAR43	Multi-functional spaces
CAR44	Use differentiation
CAR45	Mixed demographics
CAR46	Multiple/mixed tenure
CAR47	Shared ownership
CAR48	Isolatable
CAR49	Multiple access points
DS9: INCREASE INTERACTIVITY	
CAR50	Physical linkage
CAR51	Visual linkage

Table 2. Described design tactics characteristics. R.Schmidt III, S.Austin(2016)