ASSESSING THE ADAPTIVE CAPACITY AND DEMOUNTABILITY OF TIMBER STRUCTURES

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Abstract
This study assesses various prefabricated load-bearing timber structures on demountability and adaptive capacity to better understandant their performance. To achieve fair and comparable results all subjects unrelated to demountability or adaptive capacity that indirectly influence the results will be equated. For the assessment of both subjects, existing tools are used and modified to match the tested systems. Questions that compose the assessment are given a weight depending on their importance via a pairwise comparison, then scores are calculated after a stability analysis of these weights. Results show that column/beam systems have a high degree of demountability and adaptive capacity, followed by an assembly of elements. Systems built from modules score low on demountability, and also on adaptive capacity if no beams are implemented.

Keywords: demountability, flexibility, adaptive capacity

Introduction

The European Union (EU) states that CO_2 emissions should be reduced by 40% by 2030. All member states are required to be CO_2 neutral by 2050 in order to limit global warming to 1.5C (Climate action, 2021). The United Nations (UN) suggests that buildings and construction account for 40% of global CO_2 emissions (Architecture30, 2021). This is partly due to the plethora of raw materials sourced and required for a structure, of which often none can be reused once the building is demolished.

Innovation in the building industry is slow compared to other sectors such as technology or transportation, which is why it needs to reform itself with different approaches to construction and re-use materials. Supply and demand for a specific building function can quickly change. When a building is idle, the traditional construction method makes it costly and labour-intensive to transform the structure to be suitable for another function. The structure is unique and often difficult to disassemble. Despite the lifespan of a structure often being much longer than the lifespan of the building or its function, often the whole structure is demolished instead of disassembled. Since the raw materials that are required for a structure come from limited, not renewable resources, it is crucial to build future constructions in a sustainable way. Utilising buildings for their entire lifespan reduce the amount of raw resources used for construction. A flexible building can adapt to possible future changes. However, a hyper-flexible building is redundant if there is no demand for another use, hence a building should also be demountable. Ideally, every component of a building that is being disassembled should be reused in order to maximise its residual value. Therefore, this study focuses on prefab load-bearing timber structures which have various construction methods and approaches for multiple storey buildings and are assessed for their demountability and flexibility to get a better understanding of how they perform.

Methodology

To ensure sufficient in-depth analysis within the given time frame, demountability and flexibility are tested on nine load-bearing construction systems which represent the most common contemporary techniques in timber construction. It is then described how other subjects that may result in a specific method being prioritised over another, are equalised in order to obtain fair and comparable results.

DBGC (2019) has developed a tool that measures this in a building, by assessing on different scales. In addition, a distinction between technical, process-related, and financial aspects is made, although only the demountability of load-bearing structure is of relevance in this study. Similarly for demountability, adaptive capacity is first defined, then a measuring tool developed by Geraedts (2013) is partially used since this extensive method contains aspects that are not applicable for this study. Based on a selection of relevant items from this tool, a number of tests were conducted to reformulate some of the assessment questions to specifically target the main load-bearing structure. In order to analyse the correlation and reliability of the questions, the 'Cronbach's Alpha' formula is applied. This formula assesses the internal consistency of a test, in this case indicating whether the questions asked can cohesively measure the concept of adaptive capacity. However, not all the questions are equally in weight since some have a greater impact towards a higher adaptive capacity than others. Therefore a 'pair comparison' of all questions was made to determine their individual weight. In addition, a stability analysis of the weights given is performed before ranking the systems against each other.

Timber construction

Contemporary timber construction contains a wide range of structural elements and products. Mass timber-based elements such cross laminated timber (CLT) or glued-laminated timber (GLT) are the more ecological alternatives for concrete wall and floor construction. CLT enables high performances and can be precisely engineered and produced in different sizes and thicknesses (Manual, 2018). There is also dowel-laminated timber, which is further environmentally friendly due to the use of wooden pins instead of glue. Besides mass timber, there are also traditional elements such as timber frame constructions (TFC), where walls and floors are constructed of beams combined with plywood or chipboard to provide the panel with stiffness. Another major change in timber construction is the extensive prefabrication of large individual elements. Additionally to timber being a relatively light material compared to concrete and steel, it has many advantages during the manufacturing phase due to its versatility, and it can also be used structurally, as insulation, to enclose spaces, or as a finish.

Vertical and horizontal elements

Timber constructions can be divided into two categories: horizontal and vertical elements. Examples of horizontal elements are columns and walls, and vertical elements are beams and floors. Structures are often assembled from multiple techniques into a hybrid system to meet structural requirements. Combining different elements intelligently increases the freedom in design and allows timber construction to be more frequently used in complex and laborious projects. However, such a structure does not necessarily consist entirely of timber. For heavier loads and to provide stability, timber is often combined with steel. Steel joints can serve as connections between various elements, and steel strips or cables are fastened between or onto timber frames to provide rigidity.

Methods of construction

Although timber structures can be made in a traditional way, this is antiquated due to labour intensity and complexity. Nowadays, a prefabricated system allows large quantities of construction components to be produced and ready for assembly before on-site construction begins. These methods can be divided into three categories, in which the level of prefabrication and assembly differ. The first category consists of a column/beam skeleton construction that arrives at the building site in individual parts (1), which provides a high degree of flexibility and is ideal for utility buildings. The second method also involves assembly on site, but of wall and floor elements (2). This is often used in residential construction, but also in utility constructions, since individual apartments require separation which can be done by the load-bearing walls. The final method involves an assembly of modules on site (3). These are ready-to-use modules, or containers, that often include installations and sup-parts. Similar to hybrid timber systems, combinations of these methods can be made.

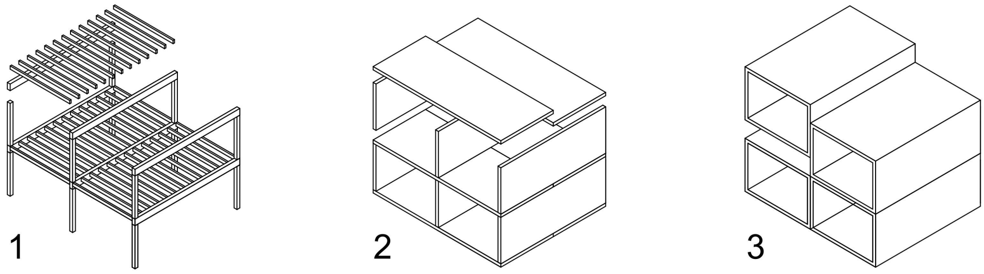


Figure 1: assembling methods

Sub-topics

Nine prefabricated timber systems are assessed in this study for their demountability and adaptive capacities. The variations in between, which differ in method or type of components or elements, are based on preliminary literature research of timber constructions. Achieving comparable results is challenging due to the many sub-topics that play a role when choosing a building system. There are various methods for connecting the vertical and horizontal elements. Most commonly, the floor or beam lies on top of the wall or column, and the latter is placed on top again. Variations of this are sometimes applied, such as half supporting or not supporting, where an element is suspended between two elements instead. However, every system considered in this research is based on stacking the prefabricated parts with full support of the underlying element.

In Geraedts' research (2013), it is advised to separate the installations from the load-bearing structure to obtain a maximum adaptive capacity. In this study, the systems are equated by using a lowered ceiling for each system, as suggested by Geraerdts. The same applies to the insulation and acoustics, which should at minimum meet the requirements of the building regulations. Challenges due to the lack of knowledge regarding fire safety must be overcome as timber grows in popularity. Since theoretically every structural component can be covered with sufficient fire resistant material to meet the minimum requirements, no further attention is paid to this issue.

This study aims to gain an understanding of how well certain timber systems perform in terms of demountability and their adaptive capacity. Other topics, such as the integration of installations or insulation that are excluded from this assessment, may be given a higher priority when choosing a load-bearing system due to financial or practical reasons. Therefore in order to assess and compare the systems justly, each is assumed to have the same way of stacking horizontal and vertical elements, equal installations, insulations, acoustics, and all meet the minimum requirements for fire safety.

Demountability

A demountable building prevents unnecessary demolishing since the components used for construction can be disassembled and re-used in other structures. Ideally, every component or element of a disassembled building should be able to be reused in order to maximise its residual value.

Definition

A structure consists of a composition of materials and elements that are connected to each other. As the use of prefabricated elements increases, the complexity of clustered elements often consequently increases (piano, 2019). Two connected elements that can be disconnected due to a detachable joint are more likely to maintain their function, and a high-quality reuse is possible if they are in good conditions. This concept is a key aspect of demountability, which is defined by Pianoo (2019) as the degree to which objects can be disassembled at all scales within works and buildings so that the object can retain its function and high-quality reuse is achievable.

Adjustments to DBGC's tool

The DBGC (2019) has developed a tool to measure the degree of demountability in a structure. For this study only the main supporting structure is of relevance, therefore process related and financial aspects are excluded from the tool. Technical factors, however, relate to the design and therefore determine the physical ability to disassemble objects. Each factor consists of several categories that are given a score, ranging from a maximum of 1.00 and a minimum of 0.10, as shown in figure 2. Four aspects of demountability are assessed: type of connections, joint accessibility, intersections, and shape encapsulation.

In the first section 'type of connections', bolt and nut joints score 0.80 since additional parts are required for attachment. However, if a component with bolt and nut connection is considered a complete component, no additional parts are applied. Therefore, any joint that does not require additional parts during assembly and disassembly is assigned a maximum score within this paper, provided that this joint leaves the component undamaged. This may apply to a steel-on-steel joint, but not to wood-on-steel. Similarly, screw joints theoretically require no additional parts, yet cause damage to the component. As long as a component remains in the same condition after disassembly as when it was assembled, it will receive the maximum score.

The same applies to the accessibility of a joint. If a component or element of the load-bearing structure is not directly accessible, but can be accessed on-site without damaging other materials, then dismantled and reused, the maximum score applies. The emphasis here is on 'on-site', as a single column or beam may be easier to dismantle than a prefabricated module. Although the individual components and elements used in prefabricated modules may be assembled with screw connections, the module cannot be disassembled on-site because accessibility is very limited due to surrounding modules. Therefore the type of joints between horizontal and vertical parts of the construction, such as walls, beams, columns and floors are of relevance . Although it can be argued that a module is first detached in its entirety and then taken apart, such a module was most likely not built to be disassembled. This is equivalent to a prefabricated assembly of components, resulting in little benefit due to limited transport dimensions.

Intersections and shape encapsulation relate to sub-parts or sections within a structure, which can be excluded as the load-bearing structure is assembled in a logical order and disassembled in reverse, so there is no shape encapsulation. Chapter 2 explains why every building should have a lowered ceiling to keep construction and installation separate from each other in order to achieve a maximum adaptive capacity. The systems within this study therefore all apply these principles, which means intersections between the load-bearing structure and installations will not occur.

Type of joint		**Weight**
Dry joint	Dry joint Click joint Magnetic joint	1,00 1,00 1,00
Joint with added elements	Bolt and nut joint (steel) Bolt and nut joint (wood) Spring joint Corner joint Screw joint	1,00 0,80 0,80 0,80 0,80
Integral joints	Pin joints Nailed joints	0,60 0,60
Soft chemical compound	Adhesive seal Foam joint (PUR)	0,20 0,20
Hard chemical compound	Adhesive bonding Fastener Welded joint Cementitious bonding Chemical anchors	0,10 0,10 0,10 0,10 0,10

Accessibility of component/element/module	**Weight**
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Figure 2: Adjusted tables based on tool by DGBC, (2019)

Adaptive capacity

A demountable structure is crucial in order to reuse elements and components. However, it is unnecessary to demolish and rebuild structures if they can adapt to new demands due to its flexible designs.

Definition

Some terms often used by architects to describe the adaptive capacity of a building are flexibility, adaptability, agility, elasticity, modularity, resilience, and versatility (Geraedts, lsson, & Hansen, 2017), of which the first two are most commonly used. In architectural terms, this can be interpreted as the physical ability to easily adapt to continuous changes in social and technical needs and patterns (Geraedts et al, 2017). Adaptability is defined by the Cambridge Dictionary as "an ability to change in order to suit different conditions". This can be complemented by the description of (Schmidt III, Eguchi, Austin, & Gibb, 2010) who states that "adaptability means the capability to adapt to new circumstances". Flexibility refers to continuous (physical) change on a small scale, whereas adaptability refers to unpredictable demands or changes, such as changing a building's function using an adaptive system (Gareadts, 2017). Both terms are and referred to as 'adaptive capacity'.

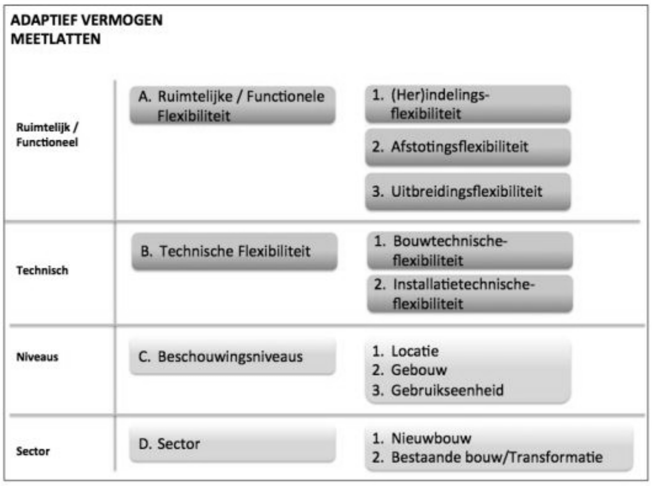


Figure 3: Overview of the measuring criteria for technical flexibility (B) that can be used as a means to achieve the objectives in the area of spatial and functional flexibility (A) at the different levels of consideration (C) for the sectors to be distinguished (D) (Geraedts, 2019)

Method of assessing

The rubric made by Geraedts (figure x.x) provides the guidelines that can be used as a framework to assess the adaptive capability of the timber building systems included in this research. As previously mentioned, not every item included in Geraedts tool is relevant for the assessments of the various load-bearing structures. The "spatial/functional" part (A) can be disregarded as it relates to the location of the structure to be assessed. Part (B), the technical flexibility, is divided into two sections: 'building flexibility' and 'installation flexibility', and can both be included in the assessment. The last 2 rows (C) and (D) indicate the 'Consideration levels' and the 'Sector', respectively. Both the building and the user units are relevant for testing newly built load-bearing structures. A summary of the applicable rubrics is as follows: B1, B2, C2, C3, D1.

Adjustments

'Horizontal grid dimensions' included in B1 of Geraedts tool assess the freedom of layout and design between two grids. However, the assessment is only applied to load-bearing elements that define the grid size, and therefore have equal building principles with regard to the free span from one grid to the other. For this reason item B1 is split into two questions, Q2 and Q3, which are reformulated to specifically address common elements of the various systems.

Grid sizes can vary depending on the building system, and Geraedts has linked dimensions to this item that result in different scores. However, in theory large spans can be obtained with any system, which emphasises the importance of assuming only economically viable and logical situations.

A low score is given for Q2 when structural elements or components have a short span, whereas a high score is given when the system uses components that are appropriate for achieving long spans.

Q3 relates to desirable future changes regarding the load-bearing structure, such as breaking through partition walls to connect spaces. A low score is obtained when the horizontal load-bearing elements offer very little to no possibilities for expansion, whereas a high score is obtained when expansion can be easily achieved without additional structural support. Assessing the possibility to connect internal walls to the façade is irrelevant since non-load bearing walls are assumed for all system's gable ends. However, testing the facades for the open/close ratio is important for the entry of daylight when a space is later divided, which is assessed with Q5.

Despite this tool covering many aspects, an additional rubric is required to arrive at a complete and correct score for the assessment of the adaptive capacity of the various building systems. When a load-bearing structure is demounted to be rebuilt elsewhere, a different composition may be desired. Therefore, Q1 assesses the adaptive capability of the mutual connections of modules, elements and parts.

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Figure 4: Adjusted tables based on tool by Geraedts (2019)

Scoring method

The instrument measures various load-bearing structures on its adaptive capacity and consists of five questions, where each is assigned a weight from 1 to 3. Q1 measures flexibility on a building scale. The main load-bearing structure should be modifiable during the design phase since every building plot has different dimensions, and urban and general requirements. This ability to change is also necessary after demounting the structure, as a different composition might be required for its new purpose.

Whilst Q1 concerns the entire system and its design capabilities, Q2 focuses on to what extent large uninterrupted spaces can be created. In theory, large spans can be achieved with any construction system. However, this might not be economically viable, hence the difference in the structural properties of the various systems should be assessed. Similar to Q2, Q3 is related to a space's dimensions by assessing to what extent there is a possibility of a space's enlargement after construction. If the load bearing structure only offers expansion in one direction the construction is limited to elongated spaces, whilst there is a greater freedom for future design changes when expansion in two directions is feasible.

Vertical alterations must also be considered, which is assessed with Q4. This allows for future toppings or a higher redesign when demanded. Q2-Q4 measure to what degree the structure lends itself to potential future alterations. As these questions consider scenarios that are post-construction only, they could be classified together. Q5 merely refers to allowing more daylight to spaces if required. In addition to every question having three answers, there is also a hierarchy of different weights per question which is determined as follows.

A simplified version of a 'pair comparison' is used where questions are compared against each other on Table X, such that between any two questions the most important one can be determined. The more relevant question is assigned a value of 2, whilst the other receives a value of 1. These numbers are then added for a total score, which is used to determine the weight of each question. The result of the weighted questionnaire allowed the nine systems to be quantitatively compared against each other, and thus ranked. In order to validate this result it is important to account for potential inaccuracies in the weight determination of each question. This is due to the nature of the specific questions formulated, thus no data has been found that resulted in precise weight values that show how each questions shows improvements towards the adaptive capacity. Therefore, to counteract and justify the approximated given weights, a stability analysis was performed.

This was conducted in the following manner. The weight of each question was altered in a +-0.5 range, with steps of 0.25, such that five weights for each question were considered. New scores were then computed for the nine systems, for all possible combinations of the weighted questions variations. This resulted in over a hundred of potential scores for each system (appendix X), which were inputed into a code that calculated the probability that a given system scored higher than another. These probabilities were then used to correct the scores into one that is immune to small fluctuations in the question's weights, which can be seen in Figure X below.

Results

Systems 1 and 3 scored the highest for demountability since columns are undamaged during disassembly when combined with steel joints. In theory, this could be applied to beams but usually only one side of the joint, either the beam or the column is provided with steel, in which most cases the latter. Furthermore, the floor elements used in systems 1 and 3 are open on the bottom side, thus can be (dis)connected to/from the wall using a joint between the beams instead of screwing from above, which is done with CLT floors (2). An assembly of CLT or TFC elements also scores high, around 0,80, due to the logical way of stacking elements on-site. Only systems formed from prefabricated modules score relatively low, around 0,50. These cannot be disassembled into components or elements on-site, only disconnected as modules from each other, hence these are designed to be reused in their entirety.

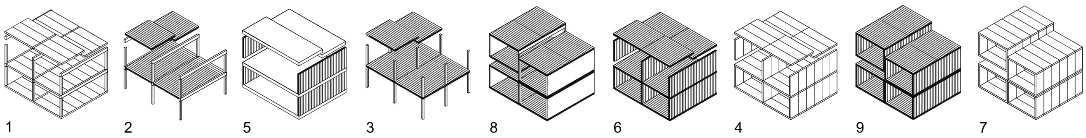
Demountability index DGBC:

- ≥ 0,40 Low demountability index;
- ≥ 0,60 Average demountability index;
- ≥ 0,80 High demountability index;

The adaptive capacity assessment's outcome concluded that systems 1 and 2 had the highest results, which are the column/beam skeletons. This may be because of the large spans and the freedom of design that comes with this system during the design phase, as well as the system's ability to change or expand post-construction. System 5 had the third highest score, constructed of GLT floors combined with CLT walls. Similar to systems 1 and 2, the laminated beams in the floors allow for large spans, whilst the CLT walls offer a high vertical load-bearing capacity for any future top-ups or taller redesigns.

Position 4 is taken by system 3 and involves an assembly of columns and CLT floors where the limited span of the floors determine the size of the grid. Only CLT floors can be self-supporting in two directions, hence removing a column without adding additional support is not possible. Although systems 7, 8, and 9 are prefabricated modules, system 8 scored considerably higher than 9 and 7. This is likely because combining columns and beams within the module allows for larger uninterrupted floor spaces once assembled. Next are systems 6 and 4, which are assemblies of elements. CLT scores higher than TFC due to its constructive properties, such as the possibility of adding future openings without structural additions. Furthermore, due to its load-bearing capacity and stability, vertical options are more likely to be achieved with CLT than TFC.

The two last systems, 9 and 7, have little flexibility compared to the others as the module is delivered prefabricated and therefore has limited sizes due to transport regulations. In addition, they are built using wall elements resulting in units with limited expansion possibilities. The five highest scoring systems all use GLT. Furthermore, TFC and CLT have mixed performances resulting in balanced scores despite large differences between the techniques.



system	1	2	5	3	8	6	4	9	7
demountability	25,67	24,33	23,67	20	19,42	18	16,42	15	10,5
adaptive capacity	0,90	0,85	0,85	0,90	0,50	0,80	0,80	0,50	0,50

Discussion

All systems have been given equal methods of stacking elements, components or modules, installations, insulations, acoustics, and fire safety to ensure fair and comparable results for demountability and adaptive capacity. This assessment is designed from an environmental and sustainability point of view, which excludes financial related issues and the aforementioned topics when analysing the structures. This is favourable to some timber systems as they would score low on the above subjects, which in reality have a greater importance than given in this study. It is possible that the higher scoring systems are considerably more expensive systems due to the extra features that are needed to meet the building regulations. These systems represent the most common combinations of hybrid timber structures, but they may also be combined. For example, a building with an open core using a column/beam skeleton surrounded by modules is an example of a structure that is not bound to one system.

Conclusion

This research shows that column/beam constructions have the highest degree of demountability due to good joint accessibility and the fact columns can be disassembled without damage. This is followed by an assembly of elements that offers good accessibility, especially in the case of open floors, as elements can be attached from below. Modules score relatively low within the assessment as they cannot be deconstructed on-site, and can only be taken apart in their entirety. Furthermore, it was found that there are minimal differences between CLT, GLT, and TFC in terms of demountability, provided that during joint design the possibility to disassemble is taken into account.

Column/beam structures also achieved the highest scores in the adaptive capacity assessment due to the large open layout of the columns and the wide spans made possible by the laminated beams. Systems 5 and 8 show that an assembly of elements or modules can also score highly, provided that laminated beams are used. The lowest scores were obtained by assemblies of elements and modules built from CLT or TFC. These systems have limited capacity for adaptation and expansion, and are limited in dimensions due to maximum span or transport requirements.

Literature

DBGC (2019*) Circular Buildings – een meetmethodiek voor losmaakbaarheid*. November 2019, versie 1.1

Durmisevic, E. (2006). *Transformable building structures*. Technische Universiteit Delft, Delft

Geraedts, R. (2013) *Adaptief Vermogen; brononderzoek - literatuurinventarisatie*. Delft, Centre for Process Innovation in Building & Construction

Geraedts R Olsson N and Hansen G K. (2017) *Adaptability*. Facilities Management and Corporate Real Estate Management as Value Drivers-How to manage and measure adding value

Kaufmann, H., Krötsch, S., & Winter, S. (2018). *Manual of Multistorey Timber Construction*. Reed Business Education.

Pianoo (2019) *Handreiking losmaakbaarheid*. Expertisecentrum Aanbesteden, Den Haag

Progress made in cutting emissions. (2021). Climate Action. Geraadpleegd op 15 september 2021, van https://ec.europa.eu/clima/eu-action/climate-strategies-targets/progress-made-cutting-emissions_en

Schmidt III, Eguchi, Austin, & Gibb (2010) *What is the meaning of adaptability in the building industry?* Loughborough University, United Kingdom

Why The Building Sector? – Architecture 2030. (2021). Geraadpleegd op 10 februari 2021, van https://architecture2030.org/why-the-building sector/#:%7E:text=Buildings%20generate%20nearly%2040%25%20of,for%20an%20additional%2011%25%20annually.

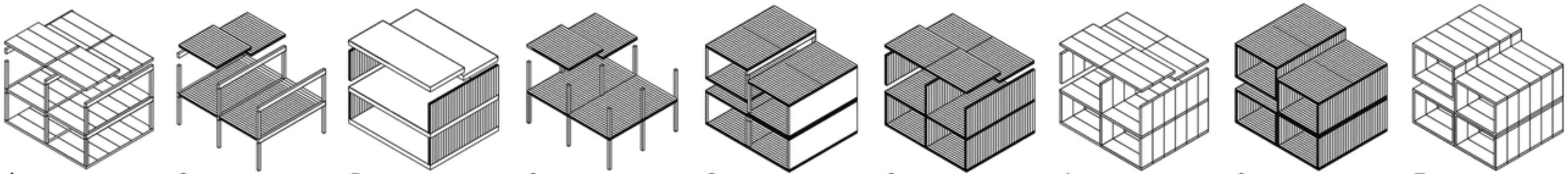
Figures

Figure 2: Adapted from: *Circular Buildings – een meetmethodiek voor losmaakbaarheid* by DBGC (2019), P10

Figure 3: (Geraedts, 2019) *Overview of the measuring criteria for technical flexibility*

Figure 4: Adapted from: *Adaptief Vermogen; brononderzoek - literatuurinventarisatie* by Geraedts, R. (2013), P56,P57

TIMBER SYSTEMS 1-9



system	1	2	5	3	8	6	4	9	7
demountability	25,67	24,33	23,67	20	19,42	18	16,42	15	10,5
adaptive capacity	0,90	0,85	0,85	0,90	0,50	0,80	0,80	0,50	0,50

Timber system 1

System 1 consists of a combination of columns and laminated beams with prefabricated floor panels that are assembled on site. The beams are fitted with a panel that provides the element with shear strength. As shown in figure x, stability cannot be obtained from a column/beam skeleton, but by using steel cables. The installations and insulation can optionally be integrated between the beams to reduce floor height, provided large diameter pipes are installed in the same direction as the beams. Such panel have limited mass, resulting in a low impact sound absorption, but their light weight allows for large spans. The columns can be directly connected with wood threaded bolts, and screws connect the floors to the beams. Because of the column/beam construction, this system has great flexibility in both the design phase as well as after construction.

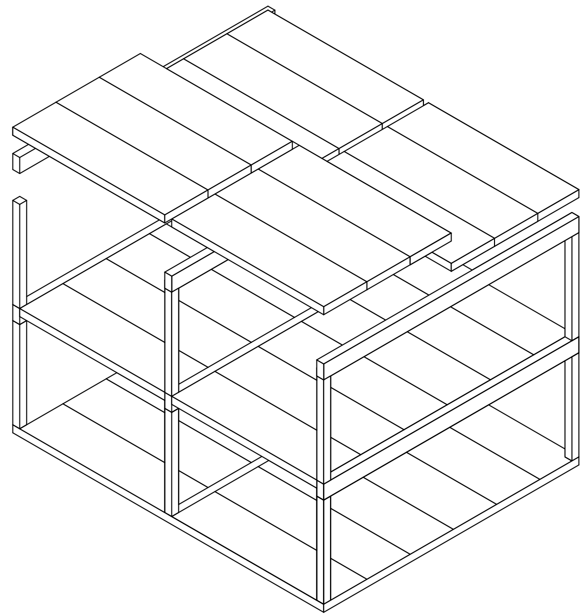


Figure 1.1: System 1 scheme

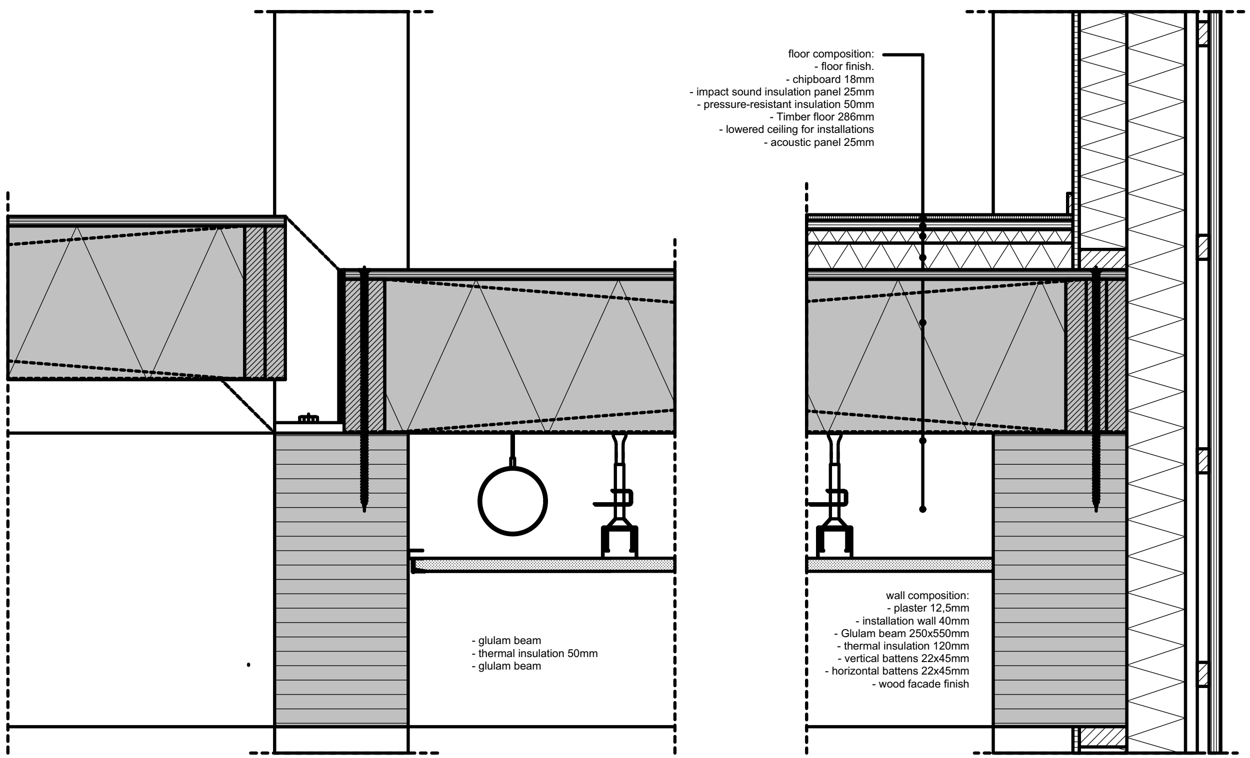


Figure 1.2: System 1 details

Figure 1.3: Column/beam construction

Timber system 1

WALL/COLUMN:

Type of joint:	bolt and nut (steel)	1,00
Accessibility joint:	freely accessible	1,00

Total: (1,0+1,0) / 2 = 1,00

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (1,0+0,8) / 2 = 0,80
Total system = 0,90

Question	Weight	Total
Q1 = 3	3	9
Q2 = 3	2	6
Q3 = 3	2	6
Q4 = 2	2	4
Q5 = 3	1	3

Maximum score = 30
System score = 28

Type of joint		Weight
Dry joint	Dry joint Click joint Magnetic joint	1,00 1,00 1,00
Joint with added elements	Bolt and nut joint (steel) Bolt and nut joint (wood) Spring joint Corner joint Screw joint	1,00 0,80 0,80 0,80 0,80
Integral joints	Pin joints Nailed joints	0,60 0,60
Soft chemical compound	Adhesive seal Foam joint (PUR)	0,20 0,20
Hard chemical compound	Adhesive bonding Fastener Welded joint Cementitious bonding Chemical anchors	0,10 0,10 0,10 0,10 0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 2

System 2 consists of a combination of columns and laminated beams, only with CLT floors instead of beams. The components and elements are assembled on site and, as shown in Figure X, rely on steel in the vertical axis for stability. A major difference between CLT and beams is the mass of the solid floors, which offers advantages with respect to impact sound, but disadvantages to the free span. The floors can easily be coupled together and transfer wind loads over large distances to a stable core by means of shear. Furthermore, CLT is fire-retardant due to the carbon layer that forms in the event of a fire. Figure X shows wood-to-wood connections, but for a fair assessment, a steel-to-wood connection is assumed, as with system 1.

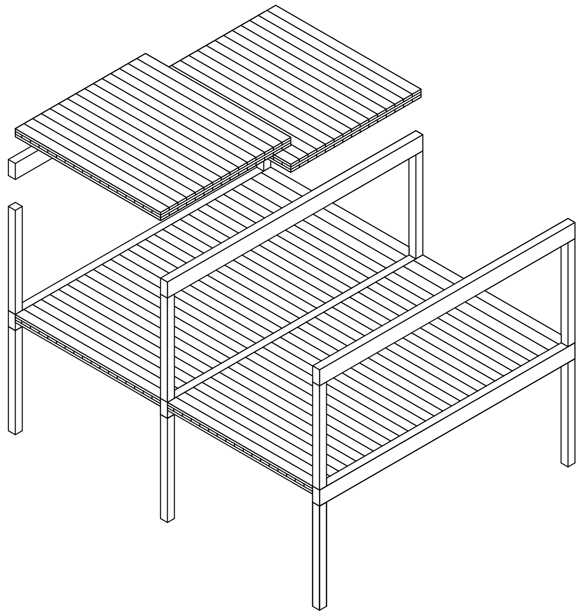


Figure 2.1: System 2 scheme

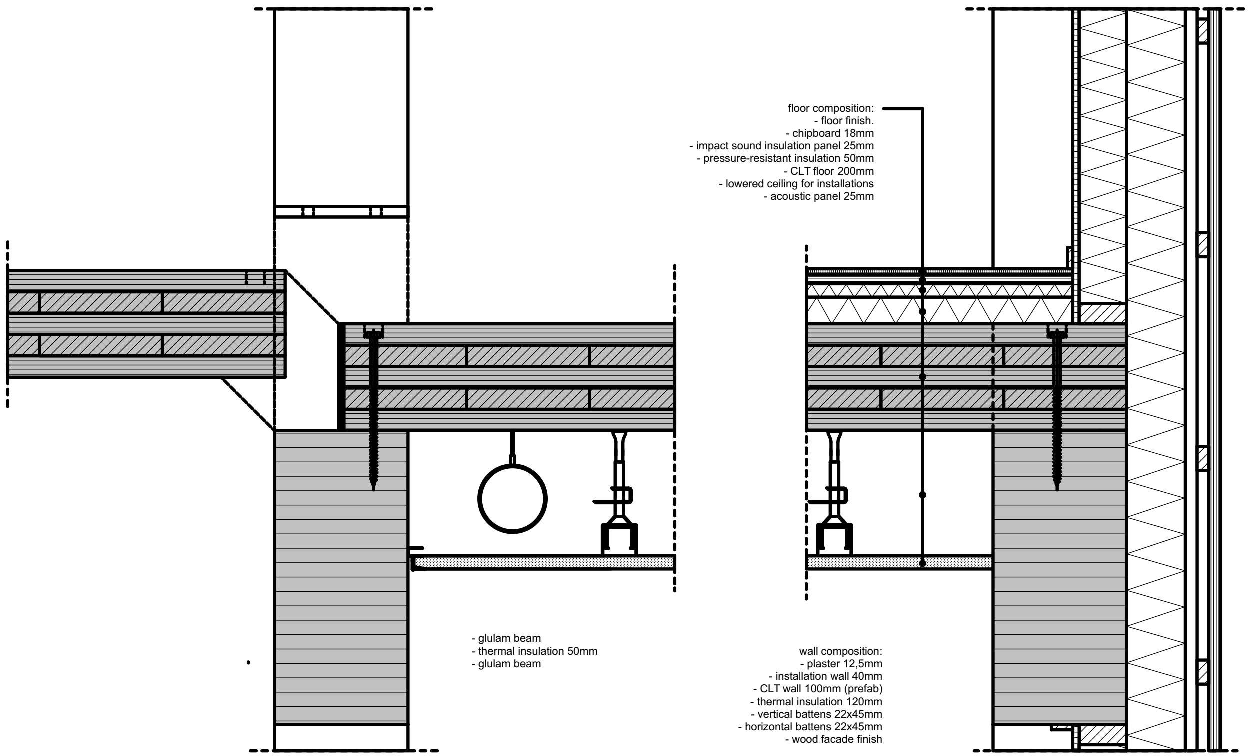


Figure 2.2: System 2 details

Figure 2.3: Column/beam construction i.c.w. CLT floors

Timber system 2

WALL/COLUMN:

Type of joint:	bolt and nut (steel)	1,00
Accessibility joint:	accessible, no damage	0,80

Total: (1,0+1,0) / 2 = 1,00

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (1,0+0,8) / 2 = 0,80

Total system = 0,90

Questions	Weight	Total
Q1 = 3	3	9
Q2 = 2	2	4
Q3 = 3	2	6
Q4 = 2	2	4
Q5 = 3	1	3

Maximum score = 30

System score = 26

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 3

System 3 is assembled on site similarly to systems 1 and 2, except that beams are not applied here, but instead CLT floor elements are attached directly to the column. This is only done with CLT floor elements as it is constructive in two directions. The absence of beams limits the maximum span of the floors, which is dependant on the constructive properties of the CLT floor. Furthermore, vertical stability must be obtained by a stable core in combination with wind braces.

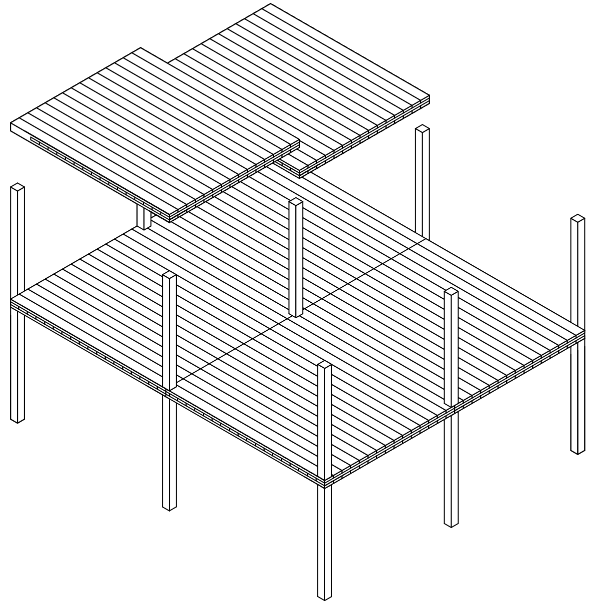


Figure 3.1: System 3 scheme

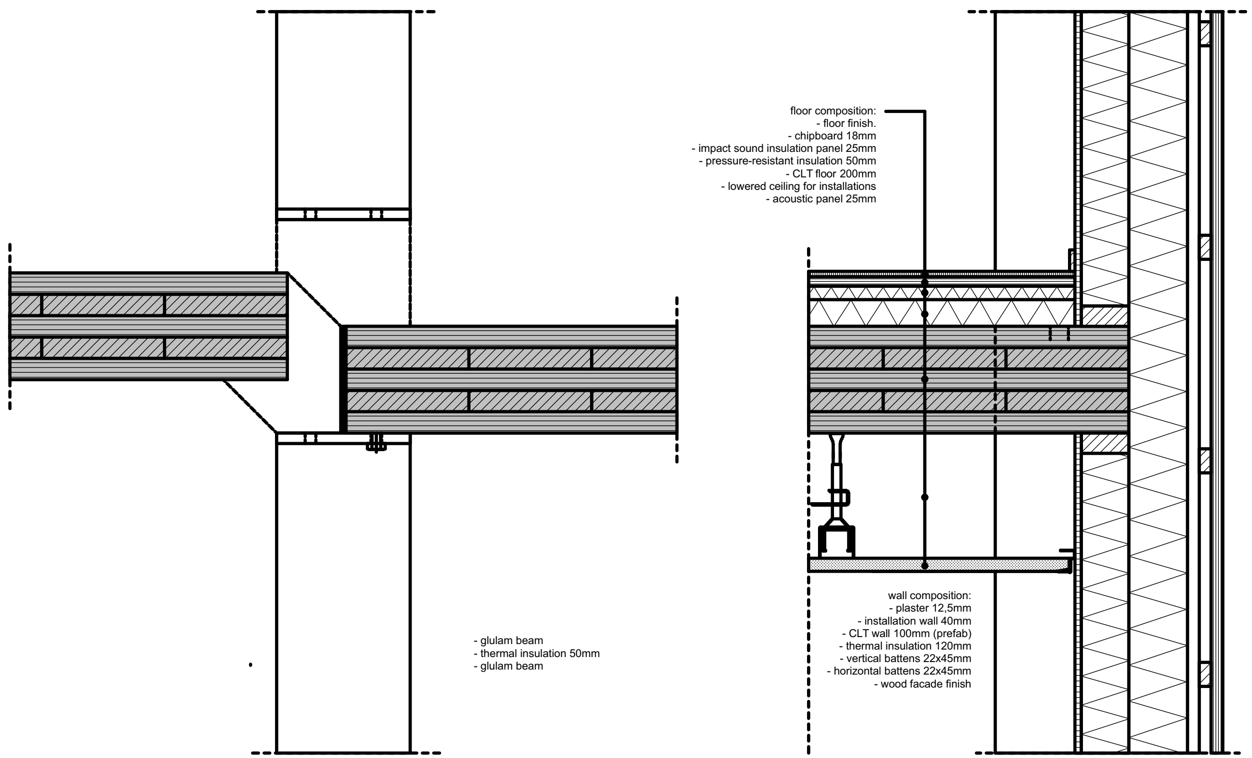


Figure 3.2: System 3 details

Figure 3.3: Columns i.c.w. CLT floors

Timber system 3

WALL/COLUMN:

Type of joint:	bolt and nut (steel)	1,00
Accessibility joint:	freely accessible	1,00

Total: (1,0+1,0) / 2 = 1,00

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (1,0+0,8) / 2 = 0,80
Total system = 0,90

Questions	Weight	Total
Q1 = 2	3	6
Q2 = 1	2	2
Q3 = 3	2	6
Q4 = 2	2	4
Q5 = 3	1	3

Maximum score = 30
System score = 21

Type of joint		Weight
Dry joint	Dry joint Click joint Magnetic joint	1,00 1,00 1,00
Joint with added elements	Bolt and nut joint (steel) Bolt and nut joint (wood) Spring joint Corner joint Screw joint	1,00 0,80 0,80 0,80 0,80
Integral joints	Pin joints Nailed joints	0,60 0,60
Soft chemical compound	Adhesive seal Foam joint (PUR)	0,20 0,20
Hard chemical compound	Adhesive bonding Fastener Welded joint Cementitious bonding Chemical anchors	0,10 0,10 0,10 0,10 0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 4

System 4 consists of an assembly of prefabricated timber frame elements for both walls and floors. These elements are made of studs or beams with a panel on at least one side to provide rigidity, which are stacked in sequence. An advantage of elements over a column/beam construction is that stability can be obtained from the elements' stiffness so no additional steel is required. Moreover, the wall also acts as the partition between two compartments, and there is a thermal break between two units which is not found in column/beam systems.

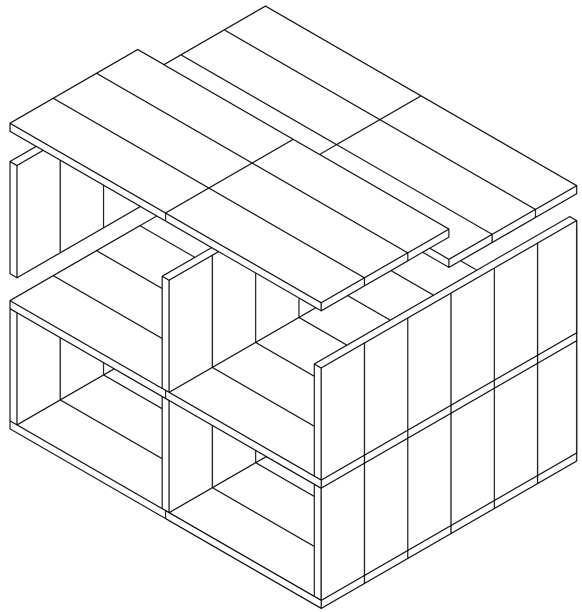


Figure 4.1: System 4 scheme

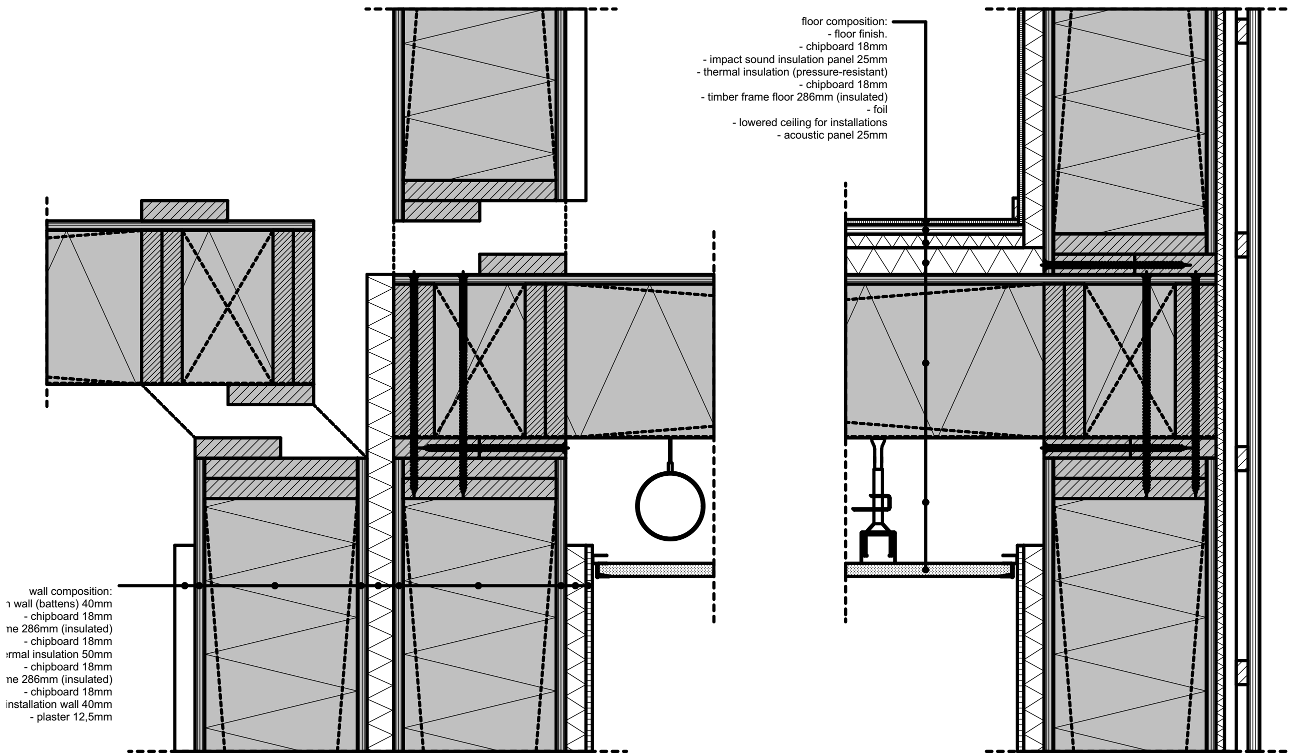


Figure 4.2: System 4 details

Figure 4.3: Timber frame construction

Timber system 4

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (0,8+0,8) / 2 = 0,80

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (0,8+0,8) / 2 = 0,80

Total system = 0,80

Questions	Weight	Total
Q1 = 3	3	9
Q2 = 1	2	2
Q3 = 2	2	4
Q4 = 1	2	2
Q5 = 1	1	1

Maximum score = 30

System score = 18

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 5

System 5 consists of CLT walls in combination with laminated beams and chipboard to provide shear strength. When a larger spacing between the beams is required, CLT flooring could be installed between the beams. This system is made of prefabricated elements, which has some advantages over columns and beams, such as the thermal breaks that can be made between different compartments. The beams have the advantage that large spans can be achieved in combination with solid CLT walls which have a high load-bearing capacity.

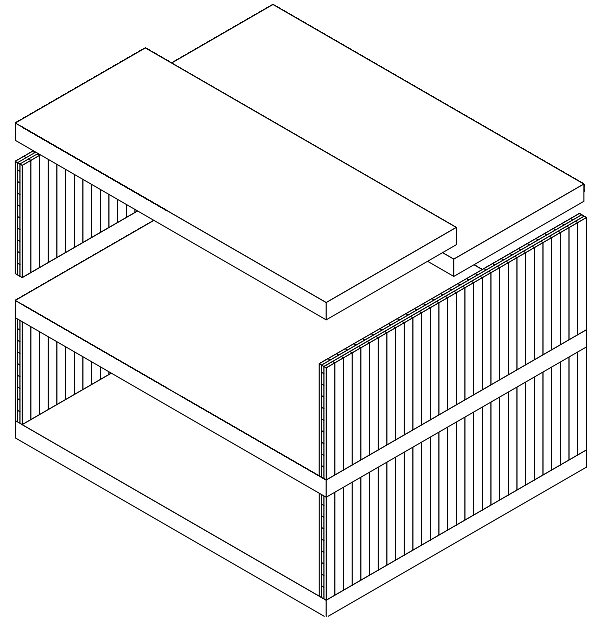


Figure 5.1: System 5 scheme

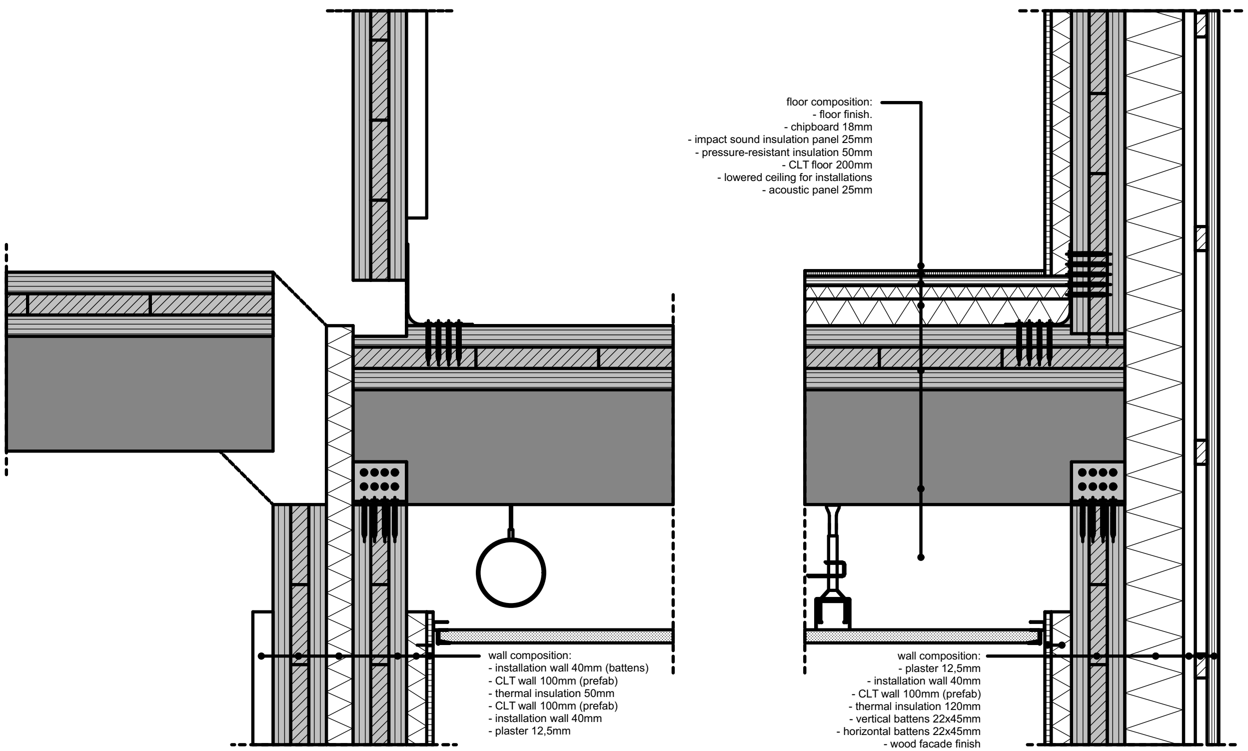


Figure 5.2: Column/beam construction details

Figure 5.3: Mass timber walls i.c.w. laminated beams

Timber system 5

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (0,8+0,8) / 2 = 0,80

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	freely accessible	1,00

Total: (0,8+1,0) / 2 = 0,90

Total system = 0,85

Question	Weight	Total
Q1 = 3	3	9
Q2 = 3	2	6
Q3 = 2	2	4
Q4 = 3	2	6
Q5 = 2	1	2

Maximum score = 30

System score = 27

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 6

System 6 consists entirely of CLT for both horizontal and vertical construction elements. The construction has a large vertical load-bearing capacity due to CLT's stiffness, thus it possesses a significant degree of stability, meaning no additional steel, or only a minimal amount, is required. Additionally from a reasonable fire resistance, CLT is occasionally chosen as the finishing layer so no additional panels are required. However, having solid elements means there is little flexibility for installation components. For the purposes of the assessment as explained in Chapter 3, all systems will have suspended ceilings in combination with installation walls. CLT elements are screwed together and are therefore slightly damaged when reused.

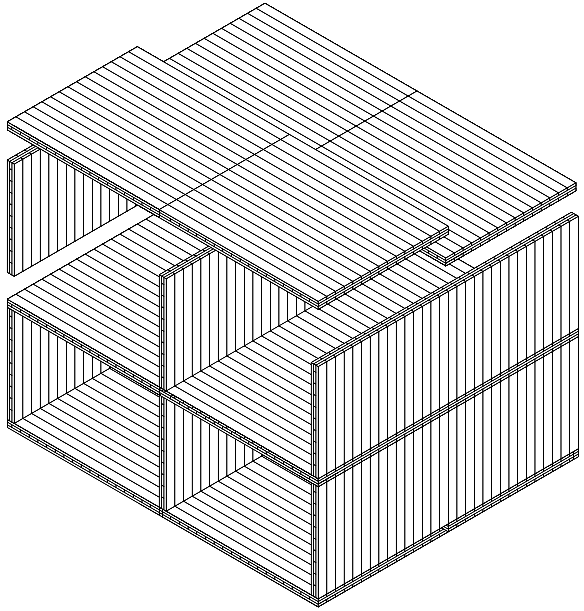


Figure 6.1: System 6 scheme

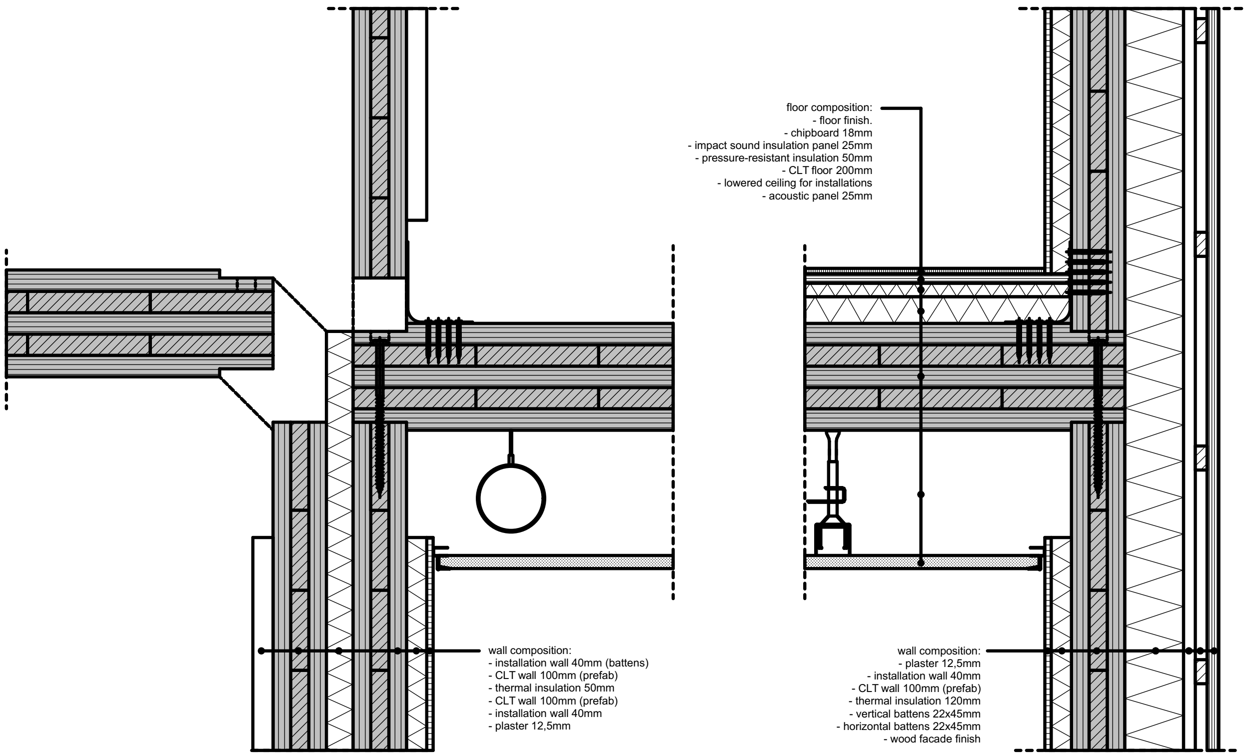


Figure 6.2: System 6 details

Figure 6.3: CLT walls and floors

Timber system 6

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (0,8+0,8) / 2 = 0,80

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	accessible, no damage	0,80

Total: (0,8+0,8) / 2 = 0,80

Total system = 0,80

Questions	Weight	Total
Q1 = 2	3	6
Q2 = 1	2	2
Q3 = 2	2	4
Q4 = 3	2	6
Q5 = 2	1	2

Maximum score = 30
System score = 20

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 7

System 7 consists only of prefabricated modules built of timber frames that are transported to the project site. The prefabricated construction design allows large parts of the installations and finishing to also be assembled in advance. However, the width of a module is limited by legal requirements with regard to the maximum transport width, hence no large dimensions are achieved. Furthermore, the modules are stacked on top of each other by crane and are coupled at each corner and/or screwed from the inside. Modules have the advantage of having a large part assembled in advance, however as each unit has a floor and a ceiling, duplicate horizontal elements occur.

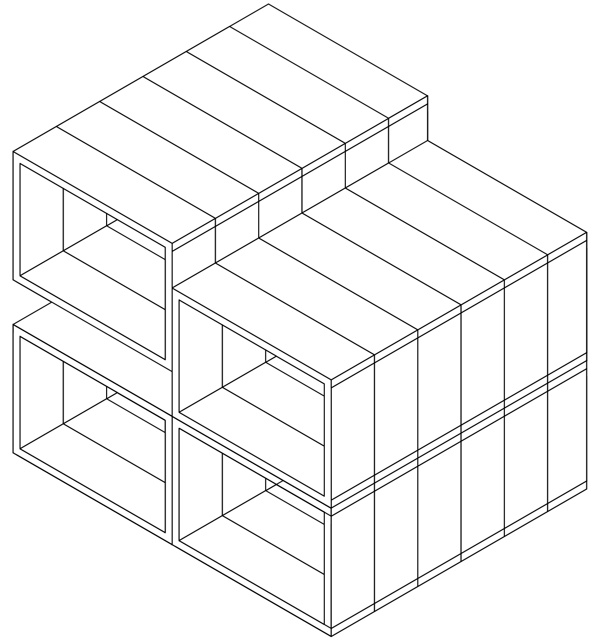


Figure 7.1: System 7 scheme

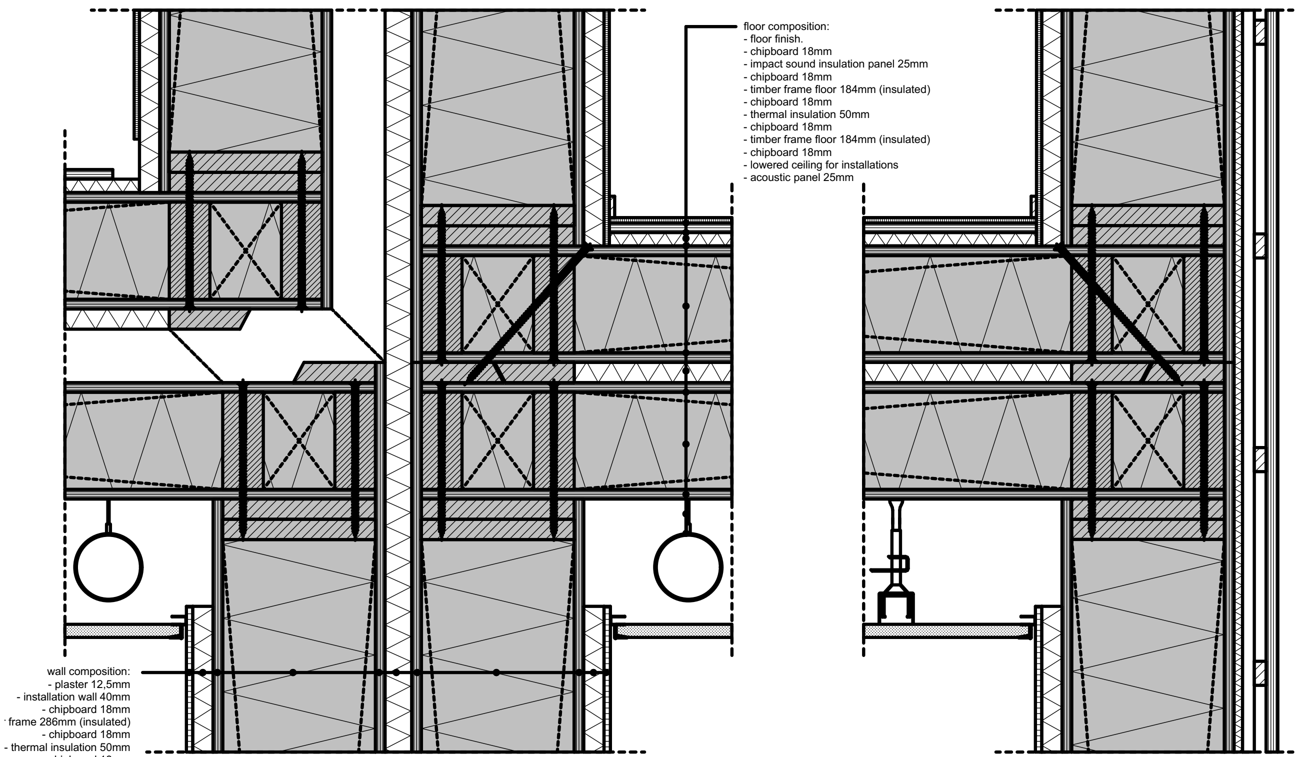


Figure 7.2: System 7 details

Figure 7.3: Prefabricated modules made of timber framing

Timber system 7

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,2) / 2 = 0,50

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,5) / 2 = 0,50
Total system = 0,50

Questions	Weight	Total
Q1 = 1	3	3
Q2 = 1	2	2
Q3 = 2	2	4
Q4 = 1	2	2
Q5 = 1	1	1

Maximum score = 30
System score = 12

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 8

System 8 is also built from prefabricated modules, only this system combines columns and beams with CLT for stability. Compared to system 7, the beams provide a large span with only support on each end, resulting in greater design freedom. However, with many open sides the stability is reduced as it is complicated to transfer wind loads over multiple modules.

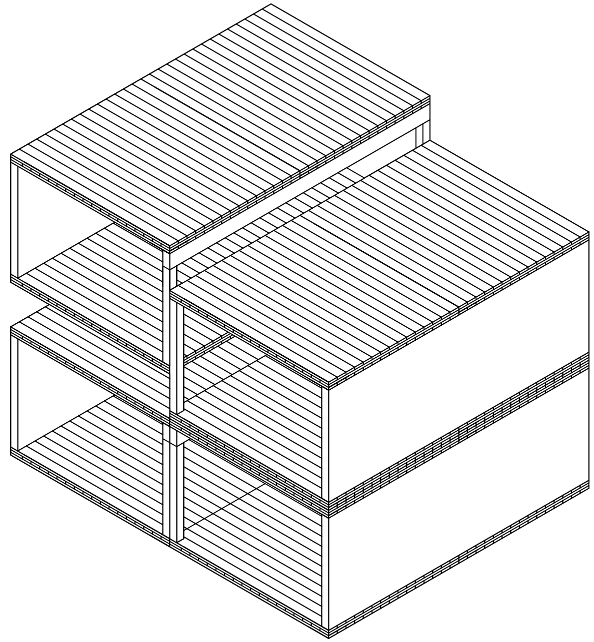


Figure 8.1: System 8 scheme

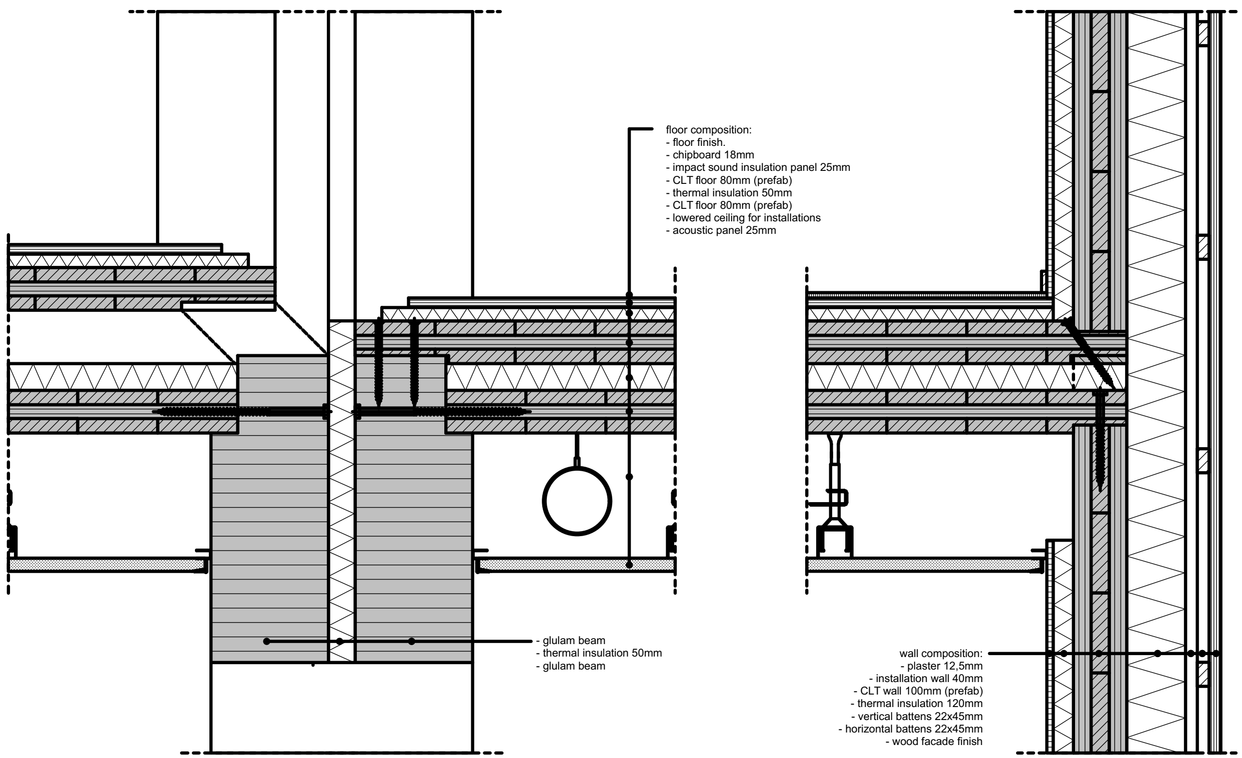


Figure 8.2: System 8 details

Figure 8.3: Ready made modules assembly

Timber system 8

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,2) / 2 = 0,50

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,5) / 2 = 0,50

Total system = 0,50

Questions	Weight	Total
Q1 = 2	3	6
Q2 = 2	2	4
Q3 = 3	2	6
Q4 = 2	2	4
Q5 = 2	1	2

Maximum score = 30

System score = 22

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Timber system 9

System 9 is similar to system 7, but made out of CLT elements. The module is limited in size due to transportation requirements. The main difference between system 9 and 7 is that CLT has a higher stiffness and stability which allows for taller structures without the use of additional constructive supports.

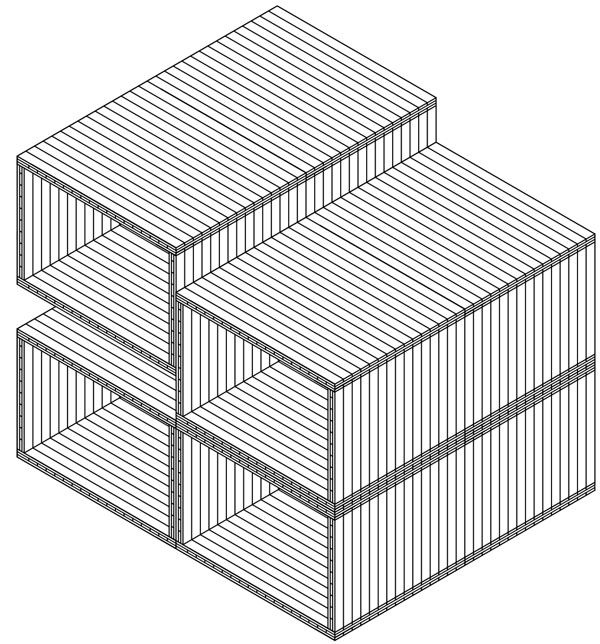


Figure 9.1: System 9 scheme

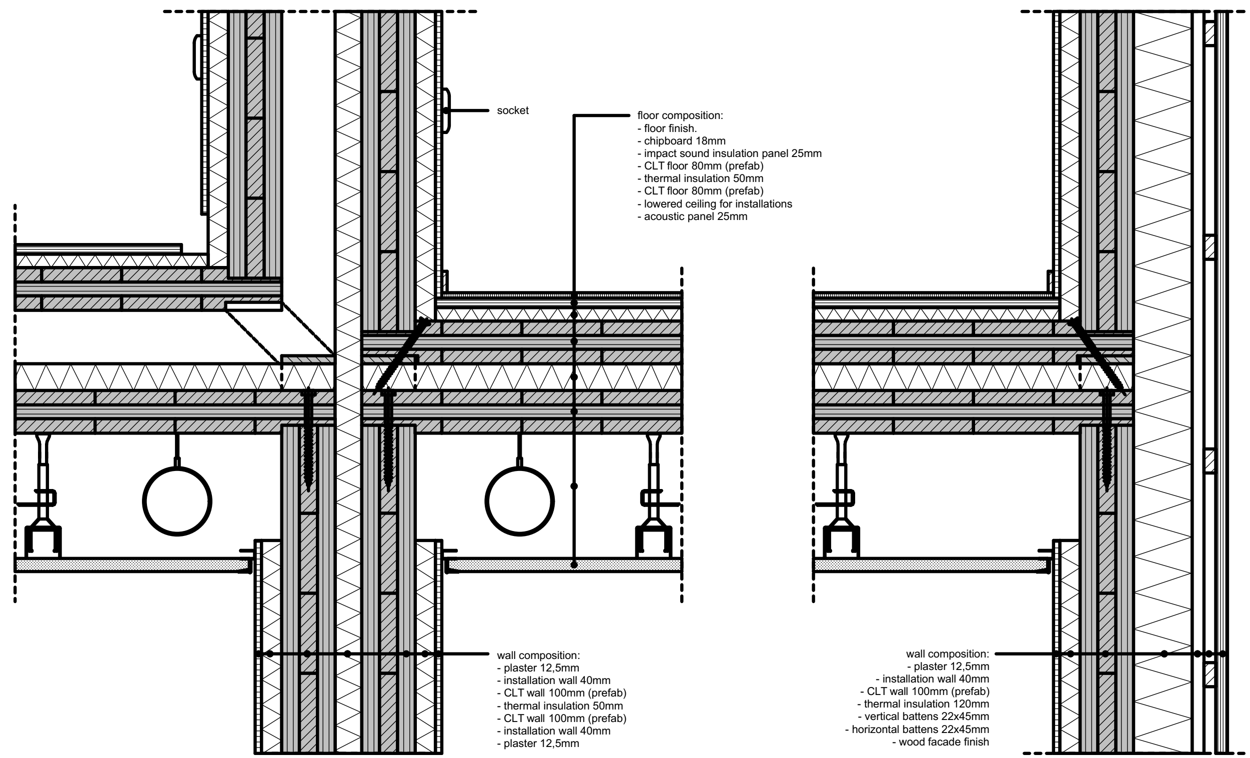


Figure 9.2: Column/beam construction details

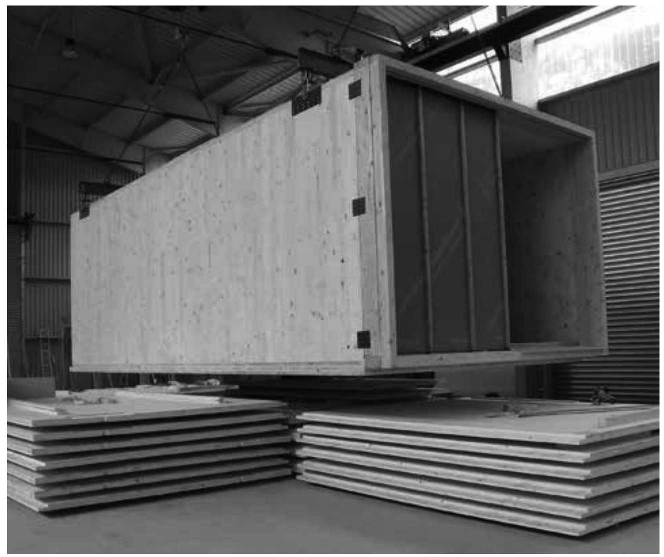


Figure 9.3: Prefabricated CLT module

Timber system 9

WALL/COLUMN:

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,2) / 2 = 0,50

FLOOR/BEAM

Type of joint:	screw joint	0,80
Accessibility joint:	irreparable damage	0,20

Total: (0,8+0,5) / 2 = 0,50
Total system = 0,50

Questions	Weight	Total
Q1 = 1	3	3
Q2 = 1	2	2
Q3 = 2	2	4
Q4 = 3	2	6
Q5 = 2	1	2

Maximum score = 30
System score = 17

Type of joint		Weight
Dry joint	Dry joint	1,00
	Click joint	1,00
	Magnetic joint	1,00
Joint with added elements	Bolt and nut joint (steel)	1,00
	Bolt and nut joint (wood)	0,80
	Spring joint	0,80
	Corner joint	0,80
	Screw joint	0,80
Integral joints	Pin joints	0,60
	Nailed joints	0,60
Soft chemical compound	Adhesive seal	0,20
	Foam joint (PUR)	0,20
Hard chemical compound	Adhesive bonding	0,10
	Fastener	0,10
	Welded joint	0,10
	Cementitious bonding	0,10
	Chemical anchors	0,10

Accessibility of component/element/module	Weight
Accessible	1,00
Accessible with additional actions that do not cause damage	0,80
Accessible with additional actions causing reparable damage	0,60
Not accessible - irreparable damage	0,20

Description	Measured values	Weight
Q1: To what extent can the load-bearing structure take on a different shape/composition during the design phase?	1. The load-bearing structure has a very limited design flexibility 2. The load-bearing structure has a sufficient design flexibility 3. The load-bearing structure has an excellent design flexibility	3
Q2: To what extent does the load-bearing structure offer the possibility for large spans?	1. The load-bearing structure is only suitable for short spans 2. The load-bearing structure is suitable for medium spans 3. The load-bearing structure is suitable for large spans	2
Q3: To what extent does the main load-bearing structure offer the possibility of an uninterrupted horizontal expansion of the space without additional constructive support?	1. No horizontal expansion can be done. 2. Expansion can be done in one direction only 3. Expansion can be done in both directions	2
Q4: To what extent does the load-bearing capacity of the structure allow vertical expansion?	1. The load-bearing structure cannot be vertically expanded without any additional support 2. The load-bearing structure allows for a limited vertical expansion with lightweight construction materials. 3. The load-bearing structure can be vertically expanded without any additional support	2
Q5: To what extent can the open/close ratio of the exterior load-bearing wall be changed?	1. The exterior load-bearing wall cannot be changed without additional support 2. The exterior load-bearing wall can be changed, but requires some minor support 3. The exterior load-bearing wall can be changed to a large extent	1

Figures

Figure 1.3: Cobouw (2020). Column/beam construction. Retrieved from: https://www.cobouw.nl/marktontwikkeling/artikel/2018/01/houten-vloeren-101256462

Figure 2.3: Woody building concepts (n.d.) Column/beam construction i.c.w. CLT floors. Retrieved from: https://www.woodybuildingconcepts.nl/projecten/nieuwbouw-houtwerk-utrecht/

Figure 3.3: Kaufmann, H., Krötsch, S., & Winter, S. (2018). Columns i.c.w. CLT

Figure 4.3: Bativox (2015) Timber frame construction. Retrieved from: https://www.bativox.be/nl/woodinc/artikel/1729/houtskeletbouw-2-0-een-stevig-houtskelet-met-unieke-wandelementen/

Figure 5.3: Kaufmann, H., Krötsch, S., & Winter, S. (2018). Mass timber walls i.c.w. laminated beams

Figure 6.3: Baumad (n.d.) CLT walls and floors. Retrieved from: http://baumad.com/2017/11/30/cenni-di-cambiamento-milan/

Figure 7.3: Stido (n.d.) Prefabricated modules made of timber framing. Retrieved from: https://www.stido.be/nl/modulaire-houtskeletbouw/houtskeletbouw/

Figure 8.3: Kaufmann, H., Krötsch, S., & Winter, S. (2018). Ready made modules assembly

Figure 9.3: Divisare (2015) Prefabricated CLT module. Retrieved from: https://divisare.com/projects/301647-ppa-architectures-philippe-ruault-50-modular-timber-apartments

Cronbach's Alpha & pairwise comparison

Multifactoriële analyse zonder herhaling

SAMENVATTING	*Aantal*	*Som*	*Gemiddelde*	*Variantie*
Rij 1	5	14	2,8	0,2
Rij 2	5	13	2,6	0,3
Rij 3	5	11	2,2	0,7
Rij 4	5	8	1,6	0,8
Rij 5	5	13	2,6	0,3
Rij 6	5	10	2	0,5
Rij 7	5	6	1,2	0,2
Rij 8	5	11	2,2	0,2
Rij 9	5	9	1,8	0,7
Kolom 1	9	20	2,222222222	0,694444444
Kolom 2	9	15	1,666666667	0,75
Kolom 3	9	22	2,444444444	0,277777778
Kolom 4	9	19	2,111111111	0,611111111
Kolom 5	9	19	2,111111111	0,611111111

Variantie-analyse

Bron van variatie	*Kwadratensom*	*Vrijheidsgraden*	*Gemiddelde kwadraten*	*F*	*P-waarde*	*Kritische gebied van F-toets*
Rijen	10,84444444	8	1,355555556	3,412587413	0,006038549	2,244396139
Kolommen	2,888888889	4	0,722222222	1,818181818	0,149610709	2,668436943
Fout	12,71111111	32	0,397222222			
Totaal	26,44444444	44				

Cronbach's Alpha = 0,706967213

	Q1	Q2	Q3	Q4	Q5	Total	Factor
Q1		2	2	2	2	**8**	**3**
Q2	1		1	2	2	**6**	**2**
Q3	1	1		2	2	**6**	**2**
Q4	1	1	1		1	**4**	**1**
Q5	1	1	1	1		**4**	**1**

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Stability analysis

System 1

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	18,50	19,83	21,17	22,50	23,83
0,75	20,00	21,33	22,67	24,00	25,33
1,00	21,50	22,83	24,17	25,50	26,83
1,25	23,00	24,33	25,67	27,00	28,33
1,50	24,50	25,83	27,17	28,50	29,83

Q1 = 2.50

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	19,25	20,58	21,92	23,25	24,58
0,75	20,75	22,08	23,42	24,75	26,08
1,00	22,25	23,58	24,92	26,25	27,58
1,25	23,75	25,08	26,42	27,75	29,08
1,50	25,25	26,58	27,92	29,25	30,58

Q1 = 2.75

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	20,00	21,33	22,67	24,00	25,33
0,75	21,50	22,83	24,17	25,50	26,83
1,00	23,00	24,33	25,67	27,00	28,33
1,25	24,50	25,83	27,17	28,50	29,83
1,50	26,00	27,33	28,67	30,00	31,33

Q1 = 3.00

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	20,75	22,08	23,42	24,75	26,08
0,75	22,25	23,58	24,92	26,25	27,58
1,00	23,75	25,08	26,42	27,75	29,08
1,25	25,25	26,58	27,92	29,25	30,58
1,50	26,75	28,08	29,42	30,75	32,08

Q1 = 3.25

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	21,50	22,83	24,17	25,50	26,83
0,75	23,00	24,33	25,67	27,00	28,33
1,00	24,50	25,83	27,17	28,50	29,83
1,25	26,00	27,33	28,67	30,00	31,33
1,50	27,50	28,83	30,17	31,50	32,83

Q1 = 3.50

System 2

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	17,50	18,67	19,83	21,00	22,17
0,75	19,00	20,17	21,33	22,50	23,67
1,00	20,50	21,67	22,83	24,00	25,17
1,25	22,00	23,17	24,33	25,50	26,67
1,50	23,50	24,67	25,83	27,00	28,17

Q1 = 2.50

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	18,25	19,42	20,58	21,75	22,92
0,75	19,75	20,92	22,08	23,25	24,42
1,00	21,25	22,42	23,58	24,75	25,92
1,25	22,75	23,92	25,08	26,25	27,42
1,50	24,25	25,42	26,58	27,75	28,92

Q1 = 2.75

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	19,00	20,17	21,33	22,50	23,67
0,75	20,50	21,67	22,83	24,00	25,17
1,00	22,00	23,17	24,33	25,50	26,67
1,25	23,50	24,67	25,83	27,00	28,17
1,50	25,00	26,17	27,33	28,50	29,67

Q1 = 3.00

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	19,75	20,92	22,08	23,25	24,42
0,75	21,25	22,42	23,58	24,75	25,92
1,00	22,75	23,92	25,08	26,25	27,42
1,25	24,25	25,42	26,58	27,75	28,92
1,50	25,75	26,92	28,08	29,25	30,42

Q1 = 3.25

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	20,50	21,67	22,83	24,00	25,17
0,75	22,00	23,17	24,33	25,50	26,67
1,00	23,50	24,67	25,83	27,00	28,17
1,25	25,00	26,17	27,33	28,50	29,67
1,50	26,50	27,67	28,83	30,00	31,17

Q1 = 3.50

System 3

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	14,00	15,00	16,00	17,00	18,00
0,75	15,50	16,50	17,50	18,50	19,50
1,00	17,00	18,00	19,00	20,00	21,00
1,25	18,50	19,50	20,50	21,50	22,50
1,50	20,00	21,00	22,00	23,00	24,00

Q1 = 2.50

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	14,50	15,50	16,50	17,50	18,50
0,75	16,00	17,00	18,00	19,00	20,00
1,00	17,50	18,50	19,50	20,50	21,50
1,25	19,00	20,00	21,00	22,00	23,00
1,50	20,50	21,50	22,50	23,50	24,50

Q1 = 2.75

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	15,00	16,00	17,00	18,00	19,00
0,75	16,50	17,50	18,50	19,50	20,50
1,00	18,00	19,00	20,00	21,00	22,00
1,25	19,50	20,50	21,50	22,50	23,50
1,50	21,00	22,00	23,00	24,00	25,00

Q1 = 3.00

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	15,50	16,50	17,50	18,50	19,50
0,75	17,00	18,00	19,00	20,00	21,00
1,00	18,50	19,50	20,50	21,50	22,50
1,25	20,00	21,00	22,00	23,00	24,00
1,50	21,50	22,50	23,50	24,50	25,50

Q1 = 3.25

Q5 Weights	Q2-Q3-Q4 Weight Variation				
	1,50	1,75	2,00	2,25	2,50
0,50	16,00	17,00	18,00	19,00	20,00
0,75	17,50	18,50	19,50	20,50	21,50
1,00	19,00	20,00	21,00	22,00	23,00
1,25	20,50	21,50	22,50	23,50	24,50
1,50	22,00	23,00	24,00	25,00	26,00

Q1 = 3.50

Stability analysis

System 4

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	12,50	13,17	13,92	14,67	15,17
0,75	13,00	13,67	14,42	15,17	15,92
1,00	13,50	14,17	14,92	15,67	16,42
1,25	14,00	14,67	15,42	16,17	16,92
1,50	14,50	15,17	15,92	16,67	17,42

Q1 = 2.50

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	13,25	13,92	14,67	15,42	15,92
0,75	13,75	14,42	15,17	15,92	16,67
1,00	14,25	14,92	15,67	16,42	17,17
1,25	14,75	15,42	16,17	16,92	17,67
1,50	15,25	15,92	16,67	17,42	18,17

Q1 = 2.75

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	14,00	14,67	15,42	16,17	16,67
0,75	14,50	15,17	15,92	16,67	17,42
1,00	15,00	15,67	16,42	17,17	17,92
1,25	15,50	16,17	16,92	17,67	18,42
1,50	16,00	16,67	17,42	18,17	18,92

Q1 = 3.00

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	14,75	15,42	16,17	16,92	17,42
0,75	15,25	15,92	16,67	17,42	18,17
1,00	15,75	16,42	17,17	17,92	18,67
1,25	16,25	16,92	17,67	18,42	19,17
1,50	16,75	17,42	18,17	18,92	19,67

Q1 = 3.25

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	15,50	16,17	16,92	17,67	18,17
0,75	16,00	16,67	17,42	18,17	18,92
1,00	16,50	17,17	17,92	18,67	19,42
1,25	17,00	17,67	18,42	19,17	19,92
1,50	17,50	18,17	18,92	19,67	20,42

Q1 = 3.50

System 5

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	17,50	18,83	20,17	21,50	22,83
0,75	18,50	19,83	21,17	22,50	23,83
1,00	19,50	20,83	22,17	23,50	24,83
1,25	20,50	21,83	23,17	24,50	25,83
1,50	21,50	22,83	24,17	25,50	26,83

Q1 = 2.50

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	18,25	19,58	20,92	22,25	23,58
0,75	19,25	20,58	21,92	23,25	24,58
1,00	20,25	21,58	22,92	24,25	25,58
1,25	21,25	22,58	23,92	25,25	26,58
1,50	22,25	23,58	24,92	26,25	27,58

Q1 = 2.75

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	19,00	20,33	21,67	23,00	24,33
0,75	20,00	21,33	22,67	24,00	25,33
1,00	21,00	22,33	23,67	25,00	26,33
1,25	22,00	23,33	24,67	26,00	27,33
1,50	23,00	24,33	25,67	27,00	28,33

Q1 = 3.00

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	19,75	21,08	22,42	23,75	25,08
0,75	20,75	22,08	23,42	24,75	26,08
1,00	21,75	23,08	24,42	25,75	27,08
1,25	22,75	24,08	25,42	26,75	28,08
1,50	23,75	25,08	26,42	27,75	29,08

Q1 = 3.25

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	20,50	21,83	23,17	24,50	25,83
0,75	21,50	22,83	24,17	25,50	26,83
1,00	22,50	23,83	25,17	26,50	27,83
1,25	23,50	24,83	26,17	27,50	28,83
1,50	24,50	25,83	27,17	28,50	29,83

Q1 = 3.50

System 6

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	13,00	14,00	15,00	16,00	17,00
0,75	14,00	15,00	16,00	17,00	18,00
1,00	15,00	16,00	17,00	18,00	19,00
1,25	16,00	17,00	18,00	19,00	20,00
1,50	17,00	18,00	19,00	20,00	21,00

Q1 = 2.50

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	13,50	14,50	15,50	16,50	17,50
0,75	14,50	15,50	16,50	17,50	18,50
1,00	15,50	16,50	17,50	18,50	19,50
1,25	16,50	17,50	18,50	19,50	20,50
1,50	17,50	18,50	19,50	20,50	21,50

Q1 = 2.75

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	14,00	15,00	16,00	17,00	18,00
0,75	15,00	16,00	17,00	18,00	19,00
1,00	16,00	17,00	18,00	19,00	20,00
1,25	17,00	18,00	19,00	20,00	21,00
1,50	18,00	19,00	20,00	21,00	22,00

Q1 = 3.00

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	14,50	15,50	16,50	17,50	18,50
0,75	15,50	16,50	17,50	18,50	19,50
1,00	16,50	17,50	18,50	19,50	20,50
1,25	17,50	18,50	19,50	20,50	21,50
1,50	18,50	19,50	20,50	21,50	22,50

Q1 = 3.25

	Q2-Q3-Q4 Weight Variation				
Q5 Weights	1,50	1,75	2,00	2,25	2,50
0,50	15,00	16,00	17,00	18,00	19,00
0,75	16,00	17,00	18,00	19,00	20,00
1,00	17,00	18,00	19,00	20,00	21,00
1,25	18,00	19,00	20,00	21,00	22,00
1,50	19,00	20,00	21,00	22,00	23,00

Q1 = 3.50

Stability analysis

System 7

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	7,50	8,25	9,00	9,75	10,50
	0,75	8,00	8,75	9,50	10,25	11,00
	1,00	8,50	9,25	10,00	10,75	11,50
	1,25	9,00	9,75	10,50	11,25	12,00
	1,50	9,50	10,25	11,00	11,75	12,50

Q1 = 2.50

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	7,75	8,50	9,25	10,00	10,75
	0,75	8,25	9,00	9,75	10,50	11,25
	1,00	8,75	9,50	10,25	11,00	11,75
	1,25	9,25	10,00	10,75	11,50	12,25
	1,50	9,75	10,50	11,25	12,00	12,75

Q1 = 2.75

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	8,50	9,25	10,00	10,75	11,50
	0,75	9,00	9,75	10,50	11,25	12,00
	1,00	9,50	10,25	11,00	11,75	12,50
	1,25	10,00	10,75	11,50	12,25	13,00
	1,50	10,50	11,25	12,00	12,75	13,50

Q1 = 3.00

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	8,00	8,75	9,50	10,25	11,00
	0,75	8,50	9,25	10,00	10,75	11,50
	1,00	9,00	9,75	10,50	11,25	12,00
	1,25	9,50	10,25	11,00	11,75	12,50
	1,50	10,00	10,75	11,50	12,25	13,00

Q1 = 3.25

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	8,25	9,00	9,75	10,50	11,25
	0,75	8,75	9,50	10,25	11,00	11,75
	1,00	9,25	10,00	10,75	11,50	12,25
	1,25	9,75	10,50	11,25	12,00	12,75
	1,50	10,25	11,00	11,75	12,50	13,25

Q1 = 3.50

System 8

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	14,00	15,17	16,33	17,50	18,67
	0,75	15,00	16,17	17,42	18,67	19,92
	1,00	16,00	17,17	18,42	19,67	20,92
	1,25	17,00	18,17	19,42	20,67	21,92
	1,50	18,00	19,17	20,42	21,67	22,92

Q1 = 2.50

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	14,50	15,67	16,83	18,00	19,17
	0,75	15,50	16,67	17,92	19,17	20,42
	1,00	16,50	17,67	18,92	20,17	21,42
	1,25	17,50	18,67	19,92	21,17	22,42
	1,50	18,50	19,67	20,92	22,17	23,42

Q1 = 2.75

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	15,00	16,17	17,33	18,50	19,67
	0,75	16,00	17,17	18,42	19,67	20,92
	1,00	17,00	18,17	19,42	20,67	21,92
	1,25	18,00	19,17	20,42	21,67	22,92
	1,50	19,00	20,17	21,42	22,67	23,92

Q1 = 3.00

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	15,50	16,67	17,83	19,00	20,17
	0,75	16,50	17,67	18,92	20,17	21,42
	1,00	17,50	18,67	19,92	21,17	22,42
	1,25	18,50	19,67	20,92	22,17	23,42
	1,50	19,50	20,67	21,92	23,17	24,42

Q1 = 3.25

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	16,00	17,17	18,33	19,50	20,67
	0,75	17,00	18,17	19,42	20,67	21,92
	1,00	18,00	19,17	20,42	21,67	22,92
	1,25	19,00	20,17	21,42	22,67	23,92
	1,50	20,00	21,17	22,42	23,67	24,92

Q1 = 3.50

System 9

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	10,50	11,50	12,50	13,50	14,50
	0,75	11,50	12,50	13,50	14,50	15,50
	1,00	12,50	13,50	14,50	15,50	16,50
	1,25	13,50	14,50	15,50	16,50	17,50
	1,50	14,50	15,50	16,50	17,50	18,50

Q1 = 2.50

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	10,75	11,75	12,75	13,75	14,75
	0,75	11,75	12,75	13,75	14,75	15,75
	1,00	12,75	13,75	14,75	15,75	16,75
	1,25	13,75	14,75	15,75	16,75	17,75
	1,50	14,75	15,75	16,75	17,75	18,75

Q1 = 2.75

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	11,00	12,00	13,00	14,00	15,00
	0,75	12,00	13,00	14,00	15,00	16,00
	1,00	13,00	14,00	15,00	16,00	17,00
	1,25	14,00	15,00	16,00	17,00	18,00
	1,50	15,00	16,00	17,00	18,00	19,00

Q1 = 3.00

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	11,25	12,25	13,25	14,25	15,25
	0,75	12,25	13,25	14,25	15,25	16,25
	1,00	13,25	14,25	15,25	16,25	17,25
	1,25	14,25	15,25	16,25	17,25	18,25
	1,50	15,25	16,25	17,25	18,25	19,25

Q1 = 3.25

		Q2-Q3-Q4 Weight Variation				
		1,50	1,75	2,00	2,25	2,50
Q5 Weights	0,50	11,50	12,50	13,50	14,50	15,50
	0,75	12,50	13,50	14,50	15,50	16,50
	1,00	13,50	14,50	15,50	16,50	17,50
	1,25	14,50	15,50	16,50	17,50	18,50
	1,50	15,50	16,50	17,50	18,50	19,50

Q1 = 3.50