A system to support the arts

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Abstract

There are often vacant old industrial buildings to be found near city centres within the Netherlands. Artists regularly use these buildings, because of a shortage of affordable and suitable atelier space. These buildings offer a grand and affordable space, but do not offer a private and comfortable structure to work in.

This article will explore the technical challenges resulting from what artist want from a space that supports their needs, and explores the realm of computer numerical controlled or CNC-routing, to analyse if the current systems that utilize this production method could provide these artists of such a space.

First the premises are defined on which the atelier structure should adhere to, using the DIY, DFD and adaptable architecture systems. These premises are used to analyse current CNC routed structural systems, where after is concluded that the current systems cannot provide the diversity that the artist would like of their atelier space. These systems ability to adapt after construction where not sufficient to shelter the changing works and needs of the artist.

This paper concludes with a conceptual proposal of an adaptable, DIY and DFD system, that can serve as a base on which a more adaptable and sufficient structure can be designed.

Keywords and notions: DIY, DFD, adaptable, CNC routing, CFU
Introduction

Often there is vacant old industrial heritage to be found near city centres in the Netherlands (van Gent hallen in Amsterdam, Lochal in Tilburg, the Spookkathedraal in Utrecht etc.). These buildings are at times in use by artists and designers who are coping with a shortage of atelier space in a time where their trade is mostly to be considered as a redundant luxury good. These buildings provide the artists with a cheap and grand space to work in, while at the same time the artists use and revitalize these old industrial buildings and their surroundings. However, although this collaboration does provide the artists with a temporary or more permanent atelier space, it does not offer a private structure and comforts of an atelier space in which the artists can work.

Proposing such a space in this context introduces several problems concerning temporality, suitability and affordability of such a structure, and the question what technique can be implemented to realise this. For this we can research the possibilities of CNC routing within the realm of digital fabrication. CNC routing has the capability to lower the costs, time and skill barrier of creating a space, by making the design, fabrication, construction and transformation accessible to the users.

To further achieve temporality, suitability, and affordability, the systems of DIY, DFD and adaptable architecture are researched. DIY for its potential to lower costs by making design independent of external parties. DFD for its ability to relocate a disassembled structure, and so allowing temporality. Finally, adaptable architecture is chosen to answer the users’ needs of atelier space that can respond to their always changing work, for example in size.

Now the question is raised: “what are the technical challenges concerning a DfD (design for disassembly), DIY (do it yourself) and adaptable building system, and what opportunities does CNC routing offer to aid in solving these challenges”. These systems are selected because of the highly versatile nature of an ideal atelier space and its users.

Although extensive academic research has explored these notions individually, there are hardly any publications to be found where these are established into relation to each other. This article will place these notions into relation to each other within a predefined context concerning the users, thus the artists and their needs, to research the opportunities which lay within CNC routing and creating a DFD, DIY and adaptable atelier space, to revitalize and use vacant industrial heritage and provide artist and designers with a structure that is suitable for their needs.

This article contains three parts. In the first part the method will be described in which the research is done. Then the here for mentioned notions will be presented into relation to the context and its users, to determine the premises onto which the CNC routing research will be defined. The third section concerns the research of current CNC routed systems and its conclusions to which end it could be suitable to provide a valid system on which a DIY, DFD and adaptable atelier space can be constructed. Concluding with the analysis of the research (by design) that is done to alter the current systems shortcomings and propose a conceptual structural system conform to the premises concerning the atelier space.

Method

The first part of the article consists of a literary study and an interview of seven artists, who all practice different forms of art, to obtain the premises on which the precedents of the second part of this chapter can be tested. The interview is held on the basis of an open question, ”If an atelier space could support you as an artists and your art, what do you want the space to do for you?”. This chapter will also include an interrelation between the DIY, DFD and adaptable architecture through clarity, feasibility and usability. These notions will be used to analyse the precedents of the second chapter,
coinciding with my own interpretation of how these works are designed and constructed, as well as being used in the third chapter, which consists of a research by design on basis of the conclusions made in the previous chapters. During these designs I have used the literary studies of other structural systems and the previously stated notions as a base to design an alternative conceptual system that can adhere to the premises gained from the interview and the literature research of the first chapter.

Findings and premises

The chosen systems carry with them certain technical challenges concerning the design and its components, as do these systems to each other. Within this chapter I establish a relation between these systems as well as a relation to the technical challenges deriving from the here for mentioned systems and the ones concerning the artists and their work. To further define the contours of the research it is key to first gain more insight into the DIY, DFD and adaptable systems and its technical consequences.

Do It Yourself

DIY is a rather broad concept with different levels of activities ranging from handcraft to home maintenance, interior decoration, interior design, customization etc.¹, thus making it important to define the boundaries to what end the artists and designers can do it their selves.

Atkins [2006] separates the activities in the groups pro-active DIY, reactive DIY, essential DIY and Lifestyle DIY²:

- **Pro-active DIY contains a significant element of self-direction, making the design and building it from raw materials.**
- **Reactive DIY consists of hobby handcraft of building activities with the focus on assembly by pattern or templates.**
- **Essential DIY consists of home maintenance activities out of necessity e.g. if one copes with a shortage of income and or professional labour.**
- **The final group is the lifestyle DIY group where the labour is by choice rather than need. This group often seeks out professional advice.**

Being in close contact with many artists and working with many of them on structures like exposition spaces, stands, sculptures, it has become clear that many artists are capable to build a basic structure but rather lack in architectural designing competence, determining its constructional capabilities and overall lack the professional ability's to install e.g. the plumbing, electric etc., putting them in the group of Reactive DIY. This means that the installations are to be installed by the professionals, as are the basic templates of the structure to be made by the architect, while the construction itself, fabrication and assemble can be done by the users. This required simplicity affects the design, production method and it documents (templates etc.), which must be easy to understand and clear so the user group can use these to build their structures.

As before stated do many artist also cope with a shortage of income, thus making DIY necessary to reduce the costs of professional help, putting them in Atkins³ Essential DIY group as well. This bears further consequences than solely “home” maintenance. As here for mentioned, it must also be possible to produce the building components. This means that the materials and production method should be affordable as well, besides being DIY, thus lightweight and relatively small so it can be handled by the users.

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Adaptability

“The term adaptable architecture describes an architecture from which specific components can be changed in response to external stimuli”\(^3\). There are several components of a design in which adaptability can play a role. Lelieveld et al. [2007]\(^4\) separates the components of a building into the groups: structure, infill, interior, technical, ambient and outfitting, of which this paper will focus more on the structure and its infill. Also he names several levels of adaptation, by hand (placing a wall, opening the blinds etc.) to fully automatic \(^4\) (for example Bill Gates’ house that reads a card in his pocket and changes the temperature, music and even opens or closes windows). Lelieveld et al. calls the most hands-on level of adaptation the level of “flexible architecture”\(^5\), which is aimed towards the adjustment of specific components, the construction and its infill. This adjustment does not have the ability to change itself, but has to be changed by the user. This system allows a more hands-on approach, thus allows a much more understandable DIY technique. However, when exactly the structure and its infill will change differs.

The interview with the artists suggests that the infill will be changing more often than the main structure, because the style of work will change less often than the works itself\(^3\). For example, autonomous artist work on various kinds of works, but will generally commit to one general idea for a longer amount of time before radically changing their style, thus possible needing to adjust the structure to accommodate the new style of work. This means that to establish a timeline, to which end adjustment is needed, it is necessary to separate the infill from the main structure. This distinction is also mentioned in Kronenburgs “Architecture in motion”\(^6\), where he suggests “adaptation by embedded flexibility”\(^7\) allows rapid changes\(^8\), and “adaptation by reconfiguration”\(^9\) allows more substantial changes.

Design for Disassembly

DFD is a strategy that can stimulate recycling, reprocessing of materials and relocation\(^9\) by making its components able to disassemble. This aspect of relocation is of most interest to this research. The artists should be able to temporarily use these old industrial building, thus making relocation the most important quality of the DFD system.

There are several technical challenges when it comes to designing for disassembly. The first challenge is that all the parts can be separated, that is mainly done by making the part interconnect, rather than binding them chemically. The second and most challenging part is the actual designing for the process of disassembly. The design must be structurally sound at every stage of disassembly, where the design must state what part will be assembled or disassembled at one time, while not compromising the construction. Key elements are the structural versus the non-structural elements, sizes and materials\(^10\) and the accessibility of its parts. While designing this it is important to make the steps conform to DIY strategy.

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The differed building processes and systems bear an interrelation to one and another. Within this there are three groups to be found that are a constant during every stage towards the end product and within the DIY, DFD and adaptable building systems: clarity, feasibility and usability.

Clarity means that the process should be clear for the user group to understand, thus making it possible for the users to understand how to go through the process of additional design (based on the provided templates supplied by the architect), fabricating, constructing the design, and using the end product.

Feasibility states to what end it is possible to be done by the user group, and is dependent of the clarity of the here for stated elements, tools, materials and components. The user group should not only be able to understand it, but should also be able to build it. This means that the tools and materials should be accessible and affordable, but also lightweight and relatively small so they can carry them and place them during construction. This weight and size requirement should also applicable when there are bigger components to be made before assembly.
Usability starts after construction and concerns to what end the design serves the user, and is dependent of the clarity of use, thus disassembly, adaptation and flexibility of its infill, but also of its feasibility to do these things concerning the amount of people who have to do this.

**CNC routed structural systems**

This chapter will look at the CNC routed structural systems that are used by Lawrence Sass in his intend house project, Pieter Stoutjesdijk’s Haiti shelter project and the Wikihouse open source project. These works will be put into relation with the here for established premises.

Every chapter will start with the background under which these projects have come about, to be followed by the design principles and its clarity, thus its components, its structuring of assembly, disassembly and jointing. Then the feasibility will be looked at, for this are accessibility, size and weight of the raw materials and components most important.

The last section will look at the usability, which mostly concern the clarity of use, adaptability of the designs and how these designs cope with the degree of flexibility and adaptability needed by my target group.

**The instant house**

*[appendix 1]*

The aim of the instant house project is to provide a novel design and prefabrication process for mass customized emergency, transitional and development contexts. This project addresses the speculative future need for housing replacements within rural areas that have been destroyed by natural disasters, or are in need for construction in general. This system is ment to aid the end user in constructing a variety of homes by providing them with a building system that can easily be produced and assembled on site within different contexts.

The instant cabin is a prototype constructed with the instant house system. The design process consists of 5 stages, shape design, design development evaluation, fabrication and construction. First the shape is determined dependent on the region, and or as one would fancy. In this case it is shaped as a run of the mail house, as it is designed as an exploratory model that serves as a control sample of the process. For the design development, the principals of the “Wood Frame Grammar” are used. This shape grammar routine transforms a shape into components that can be fabricated by a CNC router. In the evaluation stage a laser cut scaled model is made. This model assisted in the configuration sequence, testing the parts and connections and allowing the designers to evaluate the design in real space. The model was transported from CAD to EZcam for G-code generation, which drives the CNC router, where afterwards the construction can commence.

**Clarity:**

The base of the house consists of four concrete blocks on which small box columns are placed. These four sides of the columns are interlocking (friction joined) trough dado tabs and slots at the sides. The four sides are spaced and stabilized by a square component, which has four dados interlocking trough

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the four side components. The columns bear slots on which the girders are placed spanning the columns\textsuperscript{17}. These girders contain slots on where the grid structure, or waffle floor structure is formed\textsuperscript{18}. The girders and the first sections of the studs are of one element, this combined with interlocking floor panels will make a rigid base on which the rest of the building can be made. This system of interlocking floor panels trough dados on the studs and girders and slots in the panels is consisted throughout the whole design, making all the corner pieces one element, to deal with the rotational forces (moment).

The studs are build up in a circular motion, interconnected with braces in between. Stabilization is added by following every rotation by connecting the internal walls to the construction and by alternating sizes of the studs, to make sure the points of connection are not placed behind each other, thus forming a more rigid structure. The final step is to connect the outer layer of the house. This can be done by using the construction as a scaffolding to first add the cladding on the most upper part of the roof and working your way down.

When summarizing, it is shown that the majority of the building consists of several major elements, all interlocking and providing stabilization in the design as a whole, but also throughout the assembly and, if needed, the disassembly\textsuperscript{19}. The first major element is the strut that contains the slots in which the braces are placed, and the dados on which the sheeting is connected. The second major element is the sheeting. The sheeting contains the slots in which the dados of the studs are placed, and the slots in which the “biscuit”\textsuperscript{20} is placed that connect the sheeting themselves. The minor elements are the angled corner pieces that connect the studs to each other and can contain dados on which the sheeting can be connected.

It shows that the design is made out of a minimum amount of components, but also with a small amount of connection methods and possibility’s to connect, providing a clear way of constructing.

**Feasibility:**

As stated before this design is intended to be made by a minimum amount of people, thus making its parts small and light. The raw materials, thus the components are made conform to the stock size sheeting with a 0.75” (1.9mm) thickness. This makes that the studs are 4’-0” (1220mm) big, thus easily manageable for one person. The Design can be constructed by only using an mallet, this in addition of using the CNC router to make its parts.

**Usability:**

When looking at adaptability and flexibility of the design it seems that it is made to be adaptable to different circumstances in the design phase, but is not easily adaptable after it is build. The method used for the design is based on a shape design and is transformed to its parts\textsuperscript{20}. These parts can probably be used in a new design, but that does mean that the current design must be disassembled. The design is able to adapt or extend into one direction (depending of the customization of the shape), but carries no internal flexibility.

The instant house system uses no chemical bonds. This means that its parts can be disassembled without impairing the connecting components, thus materials, and one can manually assemble and disassemble the cabin with a crowbar and a mallet, thus making it rather easy to move the design between locations.

\textsuperscript{20} SASS, D. 2006. The Instant House: Design and digital fabrication of housing for developing environments. Massachusetts: Massachusetts Institute of Technology, p. 211.
The Haiti shelter
[appendix 2]

As in the project of L. Sass, this design is made to answer to a world where natural violence is becoming more common because of human caused climate change, so a cheap, flexible and quickly realizable post-disaster housing solution is needed. This is an open source system that can collectively evolve to suit different context. This solution is to be situated in de region of Villa Rosa where a 7.0 earthquake has left many people to life in tents.

Clarity:

The shelter has been designed on two overlapping grid structures of 1200mm, of which one is moved 600mm in all three directions. On this grid structure the columns are placed. In between these columns are the girders and the infill are placed. The system is a combination between a balloon frame system where the outer sheeting instead of girts, to make the building rigid, and a column and beam system. The design consists of tree types of components: structure, floors and walls.

The design comes with an assembly manual, starting at the ground floor. The first sections of the columns are placed. These sections contain the first half of a girder that is integrated with the column wall to deal with the rotational forces. The second column section will connect with the first girders hold together with a friction joint. Within these two girders is a spacer placed that interconnect the two girders, and creates a more rigid box beam (in later design to be implemented in the Wiki house). The girders are placed in between the beam, where after the floor sheeting can be connected. These steps can be repeated along the grid.

Now it is possible to extend the columns in height, of which the sides are of alternating height, so the seams between the sheets are not across from each other, to achieve more stability. The columns work with a similar system as the foundation columns of the instant house. The sides are interconnected trough dados and slots, and within are spacers placed that contain four dado’s to connect with the slots in the outer layer of the column. When extending the columns, it is possible to interconnect these with girders on which the outer cladding can be connected. This sheeting is connected to the columns by replacing one side of the column, and is connected to the girders, thus giving stabilization within the assembly and disassembly process, but also to the design. These steps seem to be repeated in a secular motion throughout assembly, where after the roofing and doors are added.

The clarity of the design is to be seen in the way of assembly. When building the first corner, one can see how to build the rest of the design (excluding the roof). One can repeat the steps to build the ground floor, but also the first floor. Its connections are all friction fit and consist merely out of dados, slots and “biscuit” like joints.

Feasibility:

The materials and components have a maximum size, conform to the maximum size of most stock sheeting of 2440mm*1220mm. This makes that all the components are suitable to be bought, fabricated (stock size is suitable for most CNC routing machines) and carried by one person.

The size of the outer sheeting is conforming to the grid size, where most of the beams are sectioned to meet in the middle (the overlaying grid), with the exception of the grindings/beams that span the
whole width of the design. These beams are sectioned on the second overlapping grid and have a span of 600mm–2400mm-600mm. This middle section seems to be the greatest span to be found in the main construction system, and conform within a stock sized sheet of 2440mm×1200mm.

Usability:

As the instant preliminary design, there seems to be a lack of flexibility and adaptability in the design ones build, which is mainly because of the roof structure.

The construction bears great adaptability because of its column and grid structure. The system used for the columns bears great potential in adapting the design. The grid can easily be expanded in the x and y direction on which the columns can be placed. The sheeting of the columns can be interchanged to sheeting bearing the girders, making it possible to add a floor. With solely this system it is possible to expand and shrink the spaces and introduce floors on the height and place where needed.

The internal flexibility is rather lacking. The pieces fit perfectly in its place but do not leave any room to introduce quick changes (flexibility) to the configuration of the spaces itself, e.g. creating a room by adding internal walls.

Assembly, disassembly and connecting its parts are of similar nature as that of the instant house method, where the elements can part by extruding the wedge, similar to the old scaffolding clamps system. There are no chemical bonds used, and all its parts can be connected by simply using a mallet. The design is meant to be able to be put together without any electronic machinery except for the CNC router. This router could be brought to such a place of disaster and produce the parts, which makes a fast and adequate house and or shelter.

WikiHouse system: Wikihouse studio, Earthquake house and Gwangju prototype
[appendix 3and 4]]

This open source construction set is aimed to allow people to create their own high performance house, by making it possible to download, adapt and print their own houses. This open source system is a way of lowering the barrier of costs, time and skill, thus making architectural design, productions and building accessible and feasible for the masses.

Clarity:

The basic structural grid of the Wikihouse system is 1200mm by 1200mm, of which the portal based structures that are of 300mm in width, are placed at every 900mm. These boxed portals can be assembled laying down, where after they are put up to connect to the other portals by girders and are, as seen before, additionally stabilized by the inner and outer sheeting.

This system has the potential to be build up to two storeys (although not tested) with a maximum room span of 3.6 meters and an maximum length of 2.4 meters and a width of 1.2 meters concerning its elements.

Three joints are introduced, the standard dado slot joints, the s-joint ("of the traditional scarf joint found in medieval Japanese joinery") and the primary connector that connects trough pegs as one would do with the old scaffolding clamps. Although this is the main structural system, it is an open

source system on which alternations have been made. There are several pavilions made through the WikiHouse system that mainly relies on this basic system.

The designs that are of most interest, are the Wikihouse studio that is truly made by this system, the Earthquake house that is made by the New Zealand Wikihouse, who transformed the shape of the main construction, and the Gwangju prototype that alters from the basic system and utilizes bolts to span, and altered the shape of the basic construction.

This design of the Wikihouse Studio is purely constructed as the guide states. It is made up out of boxed portals which are made on the ground and put up when done. They are made up out of two slabs with a spacer connected to the portals by datos trough slots. The portals itself are made up out of 6 parts. The joints are never where the most stress is (e.g. the apex and the corners). Also, the joints are not located across each other and can also be seen in the design of the Haiti house and the Instant cabin design. The two sides of the portals are first held together through the space where afterwards the girders slide trough and is connected, this to add stability. The sheeting can be placed when the portals are erected and the girders are added. The sheeting is connected to the dados of the portals and the girders, adding more stabilization.

The Earthquake house implement several changes to the basic structure, although still maintaining the main system of forming the portals, interconnecting them and adding stabilization through the sheeting. “The central idea behind the form was to maximize the internal volume while maintaining a sub consent floor area”[29]. The front and the back stick out of the 1200mm grid and the structurally lower south wall also reduces the moment around the frame to increase the overall strength of the portal design [appendix 3].

The Gwangju prototype shows that the main Wikihouse system is used, but also differs by not utilizing the boxed portals, but using bolts to make the two sides of the portal act as one. To use bolt can be considered as not a completely honest, thus not a completely CNC routed design, but is still an effective way of connecting the side to make them act as one. Using bolts is also a rather cheap, DIY, and allows DFD. Also it is an effective way of creating a tight connection where CNC routed joints can have less tolerance.

**Feasibility:**

These maximum element sizes are conforming to standardized wooden sheet measurements. This means that the element and raw material are of 18mm thickness (except for the New Zealand earthquake house, which is 19mm thick) and have a maximum size of 2400mm*1200mm, of which mostly the grid size of 1200mm*1200mm is used. The material that is used is plywood (5 layers in the earthquake house and 7 recommended by the wiki guide[29]). Due to its materials and maximum sizes it is safe to say that one person is able to carry the elements on their own, although it is not certain that one person can carry the already assembled portals on their own.

**Usability:**

The Wikihouse system has a low degree of adaptability and flexibility. The system itself can be used to generate different types of houses, but it is hard to adapt after assembly. It seems easy to add more portals and connect them, thus extending the space, but to alter the width makes a more challenging adaptation. As shown by the previous systems does the Wikihouse system not bear any internal flexibility. Its components fit perfectly to one and another, but the guide leaves no room for more infill.

[29] SCS_wikihouse_maketorium (longspan_0.30) release notes.
Conclusion

All the systems comply with the premises concerning its capability to do it yourself (DIY) and design for disassembly (DFD), but lack adaptability. The systems can be used to create different kinds of spaces, but this is mostly the case when designing. It seems rather hard to alter and or add components after the design is build, however these components can be added to the current systems.

The system that is utilized and designed by Pieter Stoutjesdijk for the Haiti shelter is most feasible to use while creating an adaptable space. The main structure used does seem to stimulate growth of the grid in the x and y direction, on which more columns can be placed, thus extending the space. Also the replacement of the outer shell of the beam columns with girder parts makes a more diverse opportunity to alter the space, although one can ask if the spans in between the columns can extend even more, being that it is only possible to extend two girders [appendix 2]. Although the extending of the girders is questionable, when introducing these columns inside of a space it is easily possible to add internal walls, making this indoor space rather flexible.

Research by design

In this chapter the “BONE structural system”\textsuperscript{30} [appendix 5] of architect A. Laval is introduced. This system contains an inherent capability of adaptation, which can close the gap between the here for analysed CNC routing building systems and my objectives following from the research in chapter one. In this chapter I will try to connect these two by designing a conceptual building system that incorporates both the CNC routed systems to the Bone structural system. First the BONE structural system will be introduced, and will be explained what makes this system suitable to close the here for mentioned gap. Afterwards the reader will be guided through the process and steps, to end with my proposed conceptual solution. This research will mainly focus on the beam and column structure, and will assume that the foot of the column is rigidly connected.

BONE system

The BONE structural system consists mainly of metal columns and girders, of which the columns have a Meccano like nature. The columns contain slots all over the sides. Because of these slots it is possible to connect the girders on every side and height. This means that wherever one would place a column it is possible to connect the girders to it and create a floor, attaching space, roof etc. This gives this system a high degree of adaptability.

This system is also rather do it yourself, when it comes to assembling its parts. Besides being a light frame building, it also consist of only two jointing system, a click and a screw system. The girders are hooked into the slot where after one can fix the girder to the column by bolting it to the column in a seated connection, thus making the connection moment resisting. This system is very clear and can be done by most people.

By translating this system to a CNC routed system, it can solve the here for mentioned deficit of adaptability concerning the previous systems. The Haiti shelter system seems to be the most promising for integration with the BONE system. Its grid structure on which the load bearing columns can (almost) be placed freely, bears the most resemblance to the BONE system\textsuperscript{30}. The differences between the two is, the ease of connecting components to its structure because of its inherent click system and the ease of creating bigger spans between the columns, thus creating bigger open spaces. This is of course also possible because of the difference of materializations.

Concept 1

The first concept looks at a way to add and retract girders to create bigger spans, and to conveying the forces of the girders to the column as a whole. The BONE system uses higher girders to create bigger spans, where I have used multiple girders. By using multiple girders there is less height needed, but also making it possible to extract two girders when only a small span is needed. The second element, or spacer, that is introduced inside of the box beam transfers half of the tensions of the added girders to the rest of the columns. (figure 2).

The main problem of this concept is the outer girders. These girders are connected to the column and can damage the structural integrity when removed. This makes that these elements are a fixed feature of the columns and do not leave room for adaptation.

Figure 2: First concept (own illustration)

Concept 2

This fixed moment is rather lost in the second concept. The girders in this concept are more easily implemented, by inserting them into the column and by fastening them with the rotating joint, making this a hinged connection.

This concept has improved on stability, strength and clarity by implementing an inner column, instead of having to insert the here for shown joints every meter. Also introducing a box beam for more stability (as can also be seen in the Haiti shelter and later on in the Wikihouse Studio).

Figure 3: 2nd concept with click system (own illustration)
The here for seen concept can be considered as a hinge, where a moment resistance is needed. The previous case studies al implement moment resistant corner solutions by making the girders part of the vertical structure. This would take a longer amount of time to implement a change, and could compromise the structural integrity of the design when changing. The next concept looks at how to solve this problem by translating already existing moment resistant connection to a CNC routed construction.

Concept 3

![Diagram of concepts 3](image)

Figure 4: research fixed moment, translation of the full depth plate, triangular haunched plate, haunched beam and a full depth end plate with a reduced beam section (own ill).

Most of the steel connections use plates and bolts and welds to connect the beams to each other. The rotational joint is used to avoid adding more and more elements, thus keeping the design clear and easy to understand. However, this joint will not be as strong as bolts and welds would be. For this, the *full depth end plate with reduced beam section* is rather interesting. This RBS system transfers part of the moment to the weakened section, as also can be seen in the flanges in a dog bone profile.

The next question is; what consequences does this column and connection design have to the main beam structure? The beam design will be based up on the here for researched click and column concept. When designing the beams structure it is important to clarify the spans it should be able to make. This design will be using a grid of 600mm*600mm, working of the standardized materials of 2440mm*1220mm and keeping in mind that sawing will inevitable take a couple of mm.

The span of the structure should be adaptable, thus raising the question to which end? When using the click system as designed previously, there will be at least three elements needed, because of the space that is needed to insert the beams (it is impossible to insert the beam as a whole with this system, as it would also become too heavy for one or two persons to do). This means that when using a column of 300mm, there will be at least a 150mm gap (see figure 5). When using three elements, there will be two points of connection between the middle part of the beam and the two parts connecting to the columns. It is safe to assume that these parts can be structurally weaker (depending on the connection method), thus it is not preferable to have more of these connections.

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Concept 4

The beam is made up from standardized wood sheeting. This means that its element cannot be longer than 2420mm, thus making the maximum span of the three elements 7260mm. The length of the beams and their adaptability depends on the elements that click into the columns. The length of these elements plus the centre piece makes up for the total span, of which the centre piece can have a length of 1800 mm to 2400mm when using the bigger outer elements, and 1200mm to 2400mm when using the smaller ones. The two outer pieces can be assembled on the ground and would weigh less as one standardized sheet.
The outer layers are connected and stabilized by the two boards through friction fit. The outer elements can be clicked into the columns, after which the centre element can be connected in between. The boards are connected with a dog-bone like joint (instant house, Sass), where after the flooring or roofing finishes the box beams by connecting on the top. Connections are added that uses bolts because this is a viable, clear and feasible way of creating a strong connection between the parts. In this instance, the centre part is placed from underneath.

The clarity of this proposal derives from a minimum of parts and joints. The columns consist of an inner spacer that also functions as an extra load carrier when bigger spans are needed. The outer plates are connected by friction fit and shows where the beam elements can be placed. The beams are separated into three parts of which the outer parts connect onto the columns and the turning joint holds them in place. The parts of the beams are (in the instance of the friction fit variant) all connected with similar joints, which are clearly shown in the beam its components.

The elements are all made out of standardized parts, and the bigger elements are of no more material than one sheet of 2440mm*1220mm, thus making those components not heavier. The tools for assembly are minimized to a hammer with the option of a wrench.

Its adaptability derives from the translation of the BONE structural system to the CNC routed columns. The main idea is that these columns can be pleased on a grid (a 600mm*600mm grid), where after the beams can be inserted in the slots that are placed all over the column, as can be seen in the BONE system. This makes it possible for fast changes, or additions, without compromising the integrity of the main structure.

The beam can differ in size, depending on where the columns are placed with a minimum span of 1200mm+600mm+1200mm to 2400mm+2400mm+2400mm. These bigger spans can be accommodated by the spacers inside of the columns and the addition of extra girders inside of the box beam.

**Conclusion**

The most important aspects of this concept are its clarity, feasibility and adaptability, as concluded in the first section of this article. The precedents that have been looked at, all contain this clarity and feasibility but seem to lack adaptability after the design phase. This conceptual proposal shows a way of introducing a high degree of adaptability within the main load bearing structure after the design phase. Although this system is conceptual (done without thorough calculation), it does give an indication of how such an adaptable system could work, what challenges such a system faces, and how they potentially can be solved, thus making this system a solid base for further design.
References

Internet:
SCS_wikihouse_maketorium (longspan_0.30) release notes.

Articles and books:
Appendix

Appendix 1

A

B

major element

studs

dado (tab)

slots for brace

(a) stud

(b) brace

(c) sheathing & connector

box joinery

slot for dado

biscuit

minor element

corner

embedded dado

d) corner

e) angle corners
Appendix 2

ASSEMBLY SEQUENCE

Sequence of assembly. Haiti shelter, P. Stoutjesdijk

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STOUTJESDIJK, P. M. M. 2014. Haiti shelter.
Appendix 3

Max piece length 2.4m
Max piece width 1.2m

Secondary connectors
Use slot in secondary connectors, especially higher up to minimise dangers of working at height.

Aren
One of the advantages of the system is that the parts under most stress are not where the joints are.

Long x, short y
For pieces which go around corners, make one side as long as possible and the other as short as possible. It improves the efficiency of sheet layouts.

Primary connectors
Located at key positions in the frame.

Design-out mistakes
Where possible, make it either impossible to put a piece in the wrong way, or not matter if you do.

General approach of design, Wikihouse

Appendix 4

Wikihouse assembly precedents: Wikihouse studio, Earthquake house and Gwangju prototype (own ill)
Appendix 4

BONE Structural system