REPOSITIONABLE ART PODIUM

TECHNICAL RESEARCH AND DESIGN OF THE REPOSITIONABLE ART PODIUM USING MODULARITY

MSc 4 graduation program Architectural Engineering
Edwin Jacobs, January 2013
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Repositionable modular buildings
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Repositionable modular buildings
INTRODUCTION

This report on the repositionable art podium is the final part of my architectural engineering graduation project at the Technical University Delft, faculty of architecture. The setup of the program prescribes two parts which both took half a year. First the technical research to gain extensive knowledge about repositionable and modular buildings (the engineering) which is later used in the second part to form starting points for the design. This is also the setup for this report. First the technical research with its conclusions and second the elaboration on the final design.

As mentioned above the field of the research is repositionable and modular structures, the reason behind choosing this topic comes from my personal fascination regarding modular buildings. In an age of environmental consciousness the efficiency prefab and modular buildings have in the construction phase is appealing but at the same time has a negative influence on the architectural values of these buildings. As our esthetical preferences pursue uniqueness and sensitive handling of the context a system requires stability and repetition to be efficient. This contradiction makes it hard to design modular buildings which perform well at both fields.

Next to the modular fascination, the word ‘repositionable’ in the title refers to another personal interest which is the globalizing world where more and more people, material, events, etc. travel from city to city for a temporal visit. Examples of such events in the past decades are the Olympic Games and the world football championships. These events provide the region with an economical and social boost but also demand a lot of support buildings being constructed to make the event possible (in the case of the Olympic games: stadiums, sport facilities, housing, etc). After the event these specialized buildings could become obsolete if not designed for adaptation. This is one approach where buildings could adapt to a new function, but another approach could be to design a building which travels to the next location to serve the same propose again and again. In this way the building can totally focus its performance on serving a single function instead of making a lot of concessions to harbor new functions in the future.

The goal I want to reach is to design a repositionable art podium which acts like the Olympic Games event mentioned earlier but takes the building with it to the next location instead of abandoning it. To do this I plan to use modularity because I see great potential in the way a modular system can adapt to its surroundings which is a quality traveling buildings should have.

Repositionable modular buildings
1.0 OBJECTIVE

To give guidance to the future design process a (imaginary) client should state an assignment that sets a goal to be fulfilled by the design. Below the intentions of this client are described in the form of a design brief followed by a problem statement, the approach taken in the technical research on the topic and at the end the research question.

1.1 DESIGN BRIEF

In 2018 The Hague is designated by the Dutch government as cultural capital of Europe. To give a boost to the artist community in The Hague the Dutch ministry of Education, Culture and Science donates an art podium to the city. This podium should provide the artists living and working in the city with a stage to exhibit their artworks and offering an insight in the actual “art level” inside the city against the art the city possesses in the form of museums and their collections. Of course the art galleries perform a similar task of displaying the actual artwork being made inside a city but they have a commercial interest clouding their judgment of which artist are good enough to be exhibited and which ones are not.

Besides the cultural aspect, as described above, the building should also be intelligent in its usage throughout the duration the building exists. To give an example which clarifies this statement we could look at how previous temporary events like the Olympic Games and the World Football Championships demanded large stadiums and other sport related facilities being build to make the event possible. After the champions are honoured the facilities often become obsolete. The ministry is very conscious about this phenomenon and together with the current economical depression in Europe (where spilling of government funds is socially not acceptable) emphasizes the continuous performance of the building, long after the initial (but temporary) designation of The Hague as cultural capital. In their vision the boost the artist community in The Hague got from the temporary art podium could also be beneficial to other cities in the Netherlands. This implies the moving of the art podium from city to city to perform again and again.

For the first location of the art podium in The Hague, Scheveningen Boulevard has been chosen. The reason is the high amount of visitors passing by which have the intention of recreating. This clear recreational mindset is susceptible to be seduced inside a museum and get in contact with new artist.
1.2 PROBLEM STATEMENT

The traveling art podium as described in the previous paragraph demands some unique qualities the building should provide. As the mission of the ministry is to provide the ‘cultural boost’ to a new city every year, the consequence is that the building should be disassembled, moved and assembled again in considerable time. To do this the building should consist of smaller parts which can be moved by truck, ship or train to the next location (assuming the building will be larger than the largest transportable dimensions). The connections between the parts should be firm (to let the parts act as a whole) but the time to assemble and disassemble them should be minimal.

Stated above are the minimal qualities the building should provide. But I want to take this assignment a step further. As the building is disassembled an enormous pile of parts will be left over. If the building is designed in a traditional way (unique building specialized to the context) many part in this pile will be unique and can only be assembled in the next location on the same spot they used to be on the previous location. This has several disadvantages, the first is the context which is changing each time the building is moved. Second is the probability that a critical part of the building gets damaged or lost in the transfer to the new location.

To overcome these disadvantages the buildings parts should be grouped by function and be interchangeable with each other so damaged parts can be easily replaced with a small collection of spare parts. The next step would be that the system is designed in such a way that it could adapt to the changing context of the new site. To give an example we can look to the Lego brick. As this is such an interchangeable system why would we disassemble the Lego structure, move the parts and assemble it again in the same way while we could adapt it to a new context (a slightly sloping hill, small ground surface, etc)

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Image 1.2.02: The annual adaptation of a building to the new context

Repositionable modular buildings
1.3 RESEARCH QUESTION

The research question which should guide the research is:

How can modularity be exploited to design efficient repositionable and form adaptable buildings?

The choice for the exploration of the field of modularity over any other temporary structure like an inflatable-, deployable- or tent-like structure has several reasons. The first is the function of the building. Where inflatable and tent-like structures can provide some shelter from the elements they do not perform well in blocking acoustics and maintaining a reasonable temperature. Something that is essential in displaying delicate artwork. Second is the form adaptation the building should subject to. In the examples of a tent or inflatable structure it is possible for fabric to contract into a small container and be moved in one piece (imagine a hot air balloon). It is illogical and more difficult to cut this fabric into smaller pieces and assemble them again the next time. Modular buildings on the contrary already need to be cut in smaller pieces to be able to move in the first place so another way of assembling is not a burden.
1.4 APPROACH RESEARCH

The technical research which is part of Architectural Engineering graduation track is dedicated to “repositionable modular buildings”. In this research the goal is to investigate the current state of repositionable buildings which use modular parts to be transported easily. The structure of the research is given below:

- Definitions
  Stating the definitions used in the research paper

- Origin
  Explaining how modularity emerged in the built environment.

- Chosen case studies
  Exploration of built modular and repositionable buildings assessed with a quick scan tool to determine they performance on different subjects giving a structured insight on what qualities or disadvantages the building has.

- Comparison
  Closer judgment of the case studies, by given criteria, to determine which qualities or lessons could be learned from the individual buildings. The most promising case studies will be closer examined in an in-depth analysis.

- In-depth analysis
  Extensive research to uncover the technical potentials inside specific buildings.
2.0 TECHNICAL RESEARCH

As paragraph “1.4 approach research” stated the technical research will be divided into several parts to give a structured overview of the usage of modular and repositionable buildings in the built environment.

2.1 DEFINITIONS

In this paragraph I will state and explain some definitions used in the research paper, this is divided in two parts. The first part consists of the actual definitions. The second describes an example which uses the definitions explaining their relations more closely.

2.1.1 DEFINITIONS USED

Whole
Assemblage of parts, components or elements belonging to a thing; the entire quantity, account, extent, or number (http://www.dictionary.com; accessed d.d. 4-6-2012)

Component
Separate element or part which provides a specific function for example, doors, stairs (http://www.encyclo.nl/begrip/component)

Module
A standardized, often interchangeable component of a system or construction that is designed for easy assembly or flexible use. (http://www.thefreedictionary.com; accessed d.d. 4-6-2012)

Prefab building
Building composed out of parts which are manufactured off-site and assembled on-site. Often this cycle can’t be repeated.

Modular building
Building composed out of standardized, often interchangeable components that are designed for easy assembly or flexible use.
Repositionable building
Building which is designed to be moved to different locations one after the other.

Repositionable modular building
Building which is designed to be moved to different locations one after the other and uses standardized, often interchangeable components that are designed for easy assembly or flexible use to do this.

The repositionable quality of the building depends on the transportability of the parts and the connection between them.
2.1.2 EXAMPLE

To give an example (so we can familiarize ourselves with the definitions used) I would like to introduce a roadmap explaining how we could develop a step by step more efficient repositionable modular wall starting from a very traditional wall; the brick wall. By doing this exorcize important variables which define modularity are exposed. By understanding this roadmap other building components could be optimized to increase their performance in repositionable quality's.

Reference point

To make a structure more efficient in its repositionable quality using modularity a point of reference should be given to compare the improvements of each step. In this example a brick wall will be used as a reference point. The brick wall could be determined as a modular wall because it fits the definition (standardized interchangable component), but the efficiency of this quality could be debated. Nevertheless it is a good example to start with because the improvements of each step are clearer.

In the schematic below the costs of a brick wall over a time period of 40 years is depicted. The costs of the wall is build up out of time (human labor) needed for construction and the materials as mortar and bricks needed to build the wall. The red symbol on the top right which shows a circular arrow and the number 40 resembles the lifecycle of the wall which means that the wall is needed on the same spot for 40 years. After this time the wall will be demolished, where again some time (labor) is needed.
Using the brick wall as a repositionable structure

When we would use this wall as a repositionable wall, meaning that the need for the wall to be in one place (lifecycle) is short, we would need to redo all the work every time the cycle is repeated. In the example below the cycle is only one year which means that after one year the brick wall would be demolished and rebuild with new labor and material. We assume that the bricks can’t be used again because they are fused with the mortar.

Where the brick wall was a very effective way of creating a wall over 40 years straight (dividing the total amount of material and time in the cycle over the years it has functioned) we now see that it has become very inefficient in doing the same thing over one year because the relatively high costs per cycle are returning each year.

![Schematic](image2.1.203) schematic on the performance (costs vs. time) of the brick wall over 40 years

![Brick Wall](image2.1.204) a brick wall is in some ways modular although every inefficient example
Improving the connection

The first thing we could do to improve the overall efficiency of the construction is to remove the material needed each cycle. As the previous model was using new bricks and mortar in every new cycle to form a new connection the “click brick” in this example is more efficient in being repositionable modular because it removes this need for new material each cycle. In the schematic below another observation that could be made is the decreasing assembly time which is caused by the easier connection between the click bricks. This assembly time is the other component besides material which assesses the connections costs.

The conclusion that could be drawn from this example is that there has been invested some additional time and material in the start of the cycle to decrease the costs in the lifecycles over time. This results in an overall more efficient repositionable wall.
Enlarging the scale

Another improvement of the repositionable modular efficiency would be to enlarge the scale of the module. A larger scale means a larger volume which results in fewer connections to be made. Imagine the click brick and how much stones you have to place until the wall is formed. It would be a lot easier (with the help of modern lifting equipment) to move fewer, but consequently heavier, building components.

In a utopian world the size of the modular blocks would be infinitely large because then the whole building could be constructed in a protected environment and moved to the building site in one piece. But, as we don’t live in that world we should look at the current state of transport technology to determine the maximum size and weight of a load. As the kind of displacement is also a factor to take into consideration (large objects are easier transported over small distances, and smaller objects are easier transported over large distances) each modular building should be reassessed to define the maximum dimensions of the modules or components.

In general there could be said that building components which travel across the country should fit inside a shipping container, as most of the cargo is shipped by freighters, trains and trucks.

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**Image 2.1.07**  schematic on the performance (costs vs. time) of the stone baskets over 40 years

**Image 2.1.08**  Gabion stone basket wall

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life cycle of modular structure

- a. time: assembly time
- d. time: dissassembly time
- material: material needed
2.2 ORIGIN

In my opinion modular buildings have had four purposes which gradually have been exploited (or “invented”) over time. These are: a technological need, an economical advantage, an esthetical expression and a functional benefit.

- Technology
Modular buildings have been around since we (as humanity) left the caves and started to construct our own structures. Because buildings are by definition larger than the human body (building: a structure which is build for human inhabitancy), the building itself is to heavy/big to be moved or created by humans in one part. Especially with the technology of early civilisations construction has to be done in parts. This is the first need for modularity. To give a example we could look towards the great pyramids. The original design contained the idea of a clean geometrical formed monolith, but because this is not possible for humans to construct at the time the building was composed of many smaller (more practical) components. So the first need for modularity could be technology driven.

- Economy
After the industrial revolution at the end of the 18th century the mass production of products and the discovery of new building materials also had their impact on construction techniques. Where buildings previously where truly craftsmanship at the construction side this shifted gradually towards construction of parts in factories to improve the efficiency of building products and reduce costs. The need for more efficient construction techniques called for more standardized components which could be mass produced by the new factories and reduced the amount of manual labour which was increasing over time because prosperity levels rouse. Towards the 20th century numerous prefab building components could be ordered to construct a building.
- Esthetics
In the late 1950s a new architectural style emerged in Japan called “metabolism”. The vision of this group of architects was based on the growing of organisms. In their opinion buildings and cities should also expand and change form as these organisms do. The traditional way of fixed forms and functions were obsolete in their view.
Although the metabolism style and its proposed changes in architectural and urban thinking where admirable, the execution of the plans was somewhat lacking the promise of a growing building and its possible benefits. As the example on the right shows the architecture gives the impression that the structure has grown organically, but in fact it follows the preconceived plan of the architect without the possibility for the building to change or grow in a natural way.
Eventually the metabolism style leans heavily on the esthetics of a modular or organic architecture and gives the world a different viewing point on how we design buildings but doesn’t take the next step towards an actually growing or changing architecture over time.

- Function/ Performance
This last purpose modular buildings have are developed around the mid 1980s when Renzo Piano designed (and build) the IBM travelling pavilion. Next to the above mentioned technical, economic and esthetical advantages of modularity, function was exploited as the pavilion could be very easily disassembled and transported to a new location. The idea behind this concept is that the building behaves more like a tent migrating from place to place where it is needed.
A critical note could be that this IBM pavilion has such an open connection with the outside environment that it hardly could be named a building. For a pavilion this is not a problem but to for a building which should protect people from negative environmental elements this structure is unqualified. The next step would be to design a more robust building which could travel across the world.
2.3 CHosen CASE STUDIES

2.3.1 QUICK SCAN

The objective of these case studies is to give an overview on modular and repositionable buildings which are built until now. The first part will consist of a number of buildings which are judged on 4 main purposes as they are explained in the previous paragraph (technical, economical, esthetical and performance). The idea is to get a quick scan over the current state of modular buildings, their qualities and shortcomings.

In the second part a matrix with all the repositionable or modular buildings from the quick scan will be formed to assess them more closely on specialized judging criteria for repositionable modular buildings.

The quick scan assessment will be conducted in the following order. Each of the four main purposes has an axis on the radar chart. When a rating is more positive the edge of gray surface will move towards the tip of the corresponding axis. Below the chart a short explanation on each judgment criteria will clarify the rating.

Technical to which extend does the modular setup of the structure have a technological advantage.

Economical to which extend does the modular setup of the structure have an economical advantage.

Esthetical to which extend does the modular setup of the structure have an esthetical quality.

Performance to which extend does the modular setup of the structure have a functional advantage.

2.3.2 CASE STUDIES

On the next pages a serie of case studies will be presented to get an insight into the modular and repositionable buildings built in the past up until the present.
QUONSET HUT

United States Navy; 1941; all over the world

TECH.  The modules can be mass produced
ECON.  The production method can be optimized in the factory
PERF.  The modular buildings used to be military barracks so they are less functional as housing units. This also applies to the curved walls.
ESTH.  The military simplistic appearance can have a negative influence which is amplified by the repetitional placement on a grid.

Image 2.3.01  Quick scan
Image 2.3.02  Abstract section of the Quonset hut
Image 2.3.03  A Quonset hut in the construction phase
Image 2.3.04  Transportation of a Quonset hut
Image 2.3.05  A neighborhood (military barracks) build up with Quonset hut's

Repositionable modular buildings
TECH. although they are prefabricated concrete units their connection and arrangement is very complicated.

ECON. the divergent modules don’t utilize the advantages of mass production.

PERF. the connection between the modules are fixed, meaning change is impossible.

ESTH. very clear architectonical translation of the metabolism style ideas (which pursued organic growth in buildings).
TECH. the identical modules allow a faster building process.
ECON. after 40 years the building is threatened to be demolished for safety reasons (asbestos, earthquake resistance) and the polluted facade.
PERF. the modules are very small and can’t be replaced by updated versions.
ESTH. very clear architectonical translation of the metabolism style ideas (which pursued organic growth in buildings).
TECH - the modules can be mass produced
ECON - the production method can be optimized in the factory
PERF - the modules are very small and not adjustable to a new context, the module is based on the mobility of the object.
ESTH - Due to its small scale and moderate anchorage to the environment the module seems to imitate the behavior of a mobile home.

Repositionable modular buildings
TECH. The modules can be mass produced
ECON. The production method can be optimized in the factory, uses shipping containers as basic modules.
PERF. The container is houses of a comfortable student residence but the modularity of the container is not fully exploited (the modules can’t be repositioned like a container). It is more a final stacking of containers.
ESTH. Playing with the depth of the modules provides a dynamic facade of shifting volumes.
TECH. the modules can be mass produced
ECON. the production method can be optimized in the factory
PERF. the modular components which form the building can actually adapt to changing needs of the occupants, unfortunately this is easier said than done.
ESTH. the strong modular expressions of the building are not only esthetic (as often happens in the metabolism style), but serve a real function.
TECH. the modules can be mass produced
ECON. the production method can be optimized in the factory
PERF. the modular load baring components of the building could change but this is counteracted by the facade that is not modular in design. But as a construction system alone it is a fine example.
ESTH. unfortunately, the modular support structure is completely separated from the facade and the buildings expression is not different to any other building.
CD20 BUILDING SYSTEM

DPO PoelBouw; 2008; Hendrik Ido Ambacht

Tech. the modules can be mass produced
Econ. the production method can be optimized in the factory
Perf. this construction system is mainly focused on quick and efficient assembly of a construc-
tion. It is a question how efficient it is in disassembling.
Esth. the modular support structure is completely separated from the facade and
the buildings expression is not different to any other building.

Image 2.3.2 34 Quick scan
Image 2.3.2 35 Abstract section of the CD20 building system
Image 2.3.2 36 The production facilities which produce the CD20 system
Image 2.3.2 37 3D drawing of the connection between columns and floors
Image 2.3.2 38 A finished building with a CD20 construction
TECH. Shipping containers are used for the transportation of the museum over the world and to build the walls of the museum.

ECON. The same museum can be used for different locations.

PERF. The museum has only one shape which is rebuild in different locations.

ESTH. The stacked shipping containers which form a wall force the visitor to think about how this temporary structure is build in contrast to the other permanent buildings around it.
DROP HOUSE

D3 architects; 2004; all over the world

TECH. by being able to contract into container sized dimensions it can be easily shipped without the need of extensive disassembly labor
ECON. temporary housing which can be reused.
PERF. the house has one shape which can be replaced around the world
ESTH. because it is a single module modularity has no influence on the esthetics of the building.
TECH. the modules can be mass produced
ECON. the production method can be optimized in the factory, installation of the modules is really fast.
PERF. a limited amount of forms can be generated with the system.
ESTH. very rudimental materials used and limited attention to esthetical details.
TECH. modules can be mass produced
ECON. by mass producing the product optimization can result in more efficient modules
PERF. the modules can be arranged in infinite ways to serve its function.
ESTH. as scaffolding is used in the construction business an esthetical quality is not required. This does not mean that it is impossible.
TECH: the modules can be produced in a factory to be assembled on site.
ECON: the modules are produced in an optimal environment.
PERF: the modularity of the building does not offer a changable structure over time.
ESTH: although the building is modular from origin the appearance of the building does not give this expression.

Repositionable modular buildings
TECH. the modules can be produced in a factory (including piping and electrical) to be assembled on site.

ECON. the modules are produced in an optimal environment.

PERF. the module shown below can not be changed that easily but the option of stacking several units on top of another in different configurations provides an adaptable structure.

ESTH. the different composition of the modules increases the diversity of the building but the material and form bind it together.

Oskar Leo Kaufmann and Albert Rüf; 2008; all over the world

Repositionable modular buildings
TECH. the parts can be produced in a factory to be assembled on site.
ECON. the parts are produced in an optimal environment.
PERF. when the parts are constructed in the factory they are assembled to form a building on site.
This makes changes in the configuration after the building is assembled impossible.
ESTH. the modular grid which is the basis of the floor plan provides the facade with some kind of order (the identical spacing’s between the columns for example).
2.4 COMPARISON

2.4.1 JUDGEMENT CRITERIA

To compare the different buildings with each other a matrix which judges and compares the buildings on several components is constructed. Below the judgement criteria of these components are described to give an insight where these ratings are based on.

PERFORMANCE

This section compares the performance of the building.

- Building program

Part describing the function of the building or structure. This could range from scaffolding structure to office building.

- Building lifecycle

This part gives an indication how long the building should service its function under normal circumstances before it is demolished or needs serious redeveloping to be current again. Below a list of functions is given with their corresponding building lifecycle.

<table>
<thead>
<tr>
<th>Building</th>
<th>Lifecycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramid of Cheops</td>
<td>(hopefully) eternal</td>
</tr>
<tr>
<td>Museum</td>
<td>200 year</td>
</tr>
<tr>
<td>House</td>
<td>60 year</td>
</tr>
<tr>
<td>IBM Pavilion</td>
<td>1 year</td>
</tr>
<tr>
<td>Beach pavilion</td>
<td>6 months</td>
</tr>
<tr>
<td>Tent</td>
<td>1 day</td>
</tr>
</tbody>
</table>
- Technical lifespan materials

Each building component has a technical lifespan. A construction made from concrete will easily last 150 years while a wooden façade without the proper maintenance will reach 1/3 of that at most. This judgment criterion will divide the structure in four parts: façade, construction, installations, layout (floor plan). All parts will be given an estimated technical lifespan resulting in an averaged technical lifespan of the building.

Common values for technical lifespan of building components.

<table>
<thead>
<tr>
<th>Site</th>
<th>eternal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>60-200 years</td>
</tr>
<tr>
<td>Façade/roof</td>
<td>30-60 years</td>
</tr>
<tr>
<td>Building service</td>
<td>5-30 years</td>
</tr>
<tr>
<td>Floor plan layout</td>
<td>5-20 years</td>
</tr>
<tr>
<td>Furniture</td>
<td>5-15 years</td>
</tr>
</tbody>
</table>

- Scale

Size of the object in comparison to its surroundings. This could range from infinitely big to infinitely small but is in the building practice confined to the range of city until detail.

As the schematic on the right shows each modular system confines itself to a particular scale. So each scale will experience the subjected part different. For example: The brick could be seen in the scale of the wall as a modular component, but a house made of bricks will not be perceived as a modular house. The brick is, on the scale of the building, a ‘molecule’ (a component so small that it can not be identified as a modular component of the building). On the other range of the spectrum the brick could be perceived as an object. For example: on
the scale of an ant the brick is a massive object which has no resemblance to the notion we have of a modular structure. The scale of the modular object has many influences on other judging aspects such as: the method of transport, speed of assembly, connection properties, etc.

- Connection

Judges how well the connection between the modular components is. If we take in mind the conclusions from chapter 2.1.2 we could divide this connection into the time needed for assembly/disassembly and the amount of material to make the connection.

> Material

The amount of material needed to facilitate the connection between two components.

The judgment scale ranges from:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>No material needed to construct the connection (for example a lego brick structure).</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ +</td>
<td>No material</td>
<td>No material needed to construct the connection (for example a lego brick structure).</td>
</tr>
<tr>
<td>+</td>
<td>Minimal material</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Avarage material</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Much material</td>
<td>Loads of material needed to construct the connection (for example a masonry wall).</td>
</tr>
<tr>
<td>- -</td>
<td>Very much material</td>
<td></td>
</tr>
</tbody>
</table>

Image 2.4.02 The modular brick needs mortar to function as a solid wall

Image 2.4.03 The modular lego bricks don’t need any material to make the connection.
> Time

The amount of time needed to construct the connection between two components.

The judgment scale ranges from:

<table>
<thead>
<tr>
<th>++</th>
<th>Minimal time</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Short time</td>
</tr>
<tr>
<td>0</td>
<td>Average time</td>
</tr>
<tr>
<td>-</td>
<td>Much time</td>
</tr>
<tr>
<td>--</td>
<td>Very much time</td>
</tr>
</tbody>
</table>

Minimal time needed to construct the connection (for example a lego brick structure).

Very much time needed to construct the connection (for example a masonry wall).

- Transport

The downside modular components have, especially modular buildings on a large scale (spaces and buildings), is that they have to be transported to the building site. If the building would be constructed on a traditional way this would also be a problem but the material is shipped in a very dense package (see picture on the right 2.4.1 04) so the main focus of the transport is weight.

The additional problem modular spaces and buildings have in transport is the volume of the modular component. Besides the weight of the materials used this material already has been arranged in a space defining structure. The result is that you are moving a lot of space (see picture on the right 2.4.1 05).

In today’s construction practice oversized prefabricated parts are transported over short distances by trailer or boat. The large costs of the oversized transport are reduced by choosing the manufacturer which is closest to the construction site. By doing so the length of the route is shortened as are the costs.
Taken the text written above into account transport of modular buildings or components could be judged on two aspects:

> Weight

Weight of a single shipment.

The judgment scale ranges from:

| + + | Very low weight | For example a composite structure. |
| +   | Low weight      |                                  |
| 0   | Average weight  |                                  |
| -   | Heavy weight    |                                  |
| - - | Very heavy weight | For example a concrete building.  |

> Dimensions

Dimensions of a single shipment

The judgment scale ranges from:

| + + | Very practical dimensions | For example multiple components that fit on a standard size trailer. |
| +   | Practical dimensions      |                                  |
| 0   | Average dimensions        |                                  |
| -   | Unpractical dimensions    |                                  |
| - - | Very unpractical dimensions | For example the shipment of a component that is 10 x 10 x 10 m (a house). |
In this section an estimation on the economic performance of the building will be made. As the economic value of a building or building component is hard to quantify (especially for non economists) the judgment will not be as founded as the other sections. Nevertheless it can be estimated how high the economical efficiency is by comparing how much material and time there is spent to construct the building versus the time it has served a profitable purpose.

The judgment scale ranges from:

| + + | Highly economical | Low building costs and lifecycle above expectations. |
| +   | Economical         |
| O    | Avaragly economical |
| -    | Uneconomical       |
| - -  | Highly uneconomical | High building costs and lifecycle below expectations. |

Although esthetics are generally subjective qualities of a building or structure they should be addressed in this architectural case study because they influence the building lifespan, economics, building function, etc. To give an example: An esthetically revolting building could be prematurely demolished although it was very economical, functional and technically sound. The opposite could also happen with a very esthetically appealing building where people feel affection for and care for it. To give a structure to the esthetical judgment it is divided in four parts: from, material, diversity and details.
- **Form**

Judging the form of the structure.

| + + | Very appealing form |
| +  | Appealing form |
| 0  | Average form |
| -  | Revolting form |
| - - | Very revolting form |

- **Composition/Diversity**

Judging the diversity of the structure.

| + + | Very appealing diversity |
| +  | Appealing diversity |
| 0  | Average diversity |
| -  | Revolting diversity |
| - - | Very revolting diversity |

- **Material**

Judging the material the structure is made from.

| + + | Very appealing material |
| +  | Appealing material |
| 0  | Average material |
| -  | Revolting material |
| - - | Very revolting material |

- **Detail**

Judging how much attention was given to the details of the structure.

| + + | Very much attention |
| +  | Much attention |
| 0  | Average attention |
| -  | Lacking attention |
| - - | No attention |
## 2.4.2 COMPARISON MATRIX

<table>
<thead>
<tr>
<th>PERFORMANCE</th>
<th>TECHNICAL</th>
<th>ECONOMICS</th>
<th>ESTHETICS</th>
<th>CONCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BUILDING</strong></td>
<td><strong>SCALE</strong></td>
<td><strong>CONNECTION</strong></td>
<td><strong>TRANSPORT</strong></td>
<td><strong>FORM</strong></td>
</tr>
<tr>
<td><strong>PROGRAM</strong></td>
<td><strong>BUILDING</strong></td>
<td><strong>TECHNICAL REQUIREMENTS</strong></td>
<td><strong>DIMENSION</strong></td>
<td><strong>WEIGHT</strong></td>
</tr>
<tr>
<td><strong>MILITARY</strong></td>
<td>2 - 5 YEARS</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>BARACKS</strong></td>
<td>BUILDING</td>
<td>BUILDING</td>
<td>BUILDING</td>
<td>BUILDING</td>
</tr>
<tr>
<td><strong>COSTS</strong></td>
<td><strong>40 YEARS</strong></td>
<td><strong>50 YEARS</strong></td>
<td><strong>60 YEARS</strong></td>
<td><strong>80 YEARS</strong></td>
</tr>
<tr>
<td><strong>SPACE</strong></td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>APARTMENTS</strong></td>
<td>30 YEARS</td>
<td>30 YEARS</td>
<td>30 YEARS</td>
<td>30 YEARS</td>
</tr>
<tr>
<td><strong>METASTAT SYSTEM</strong></td>
<td>70 YEARS</td>
<td>70 YEARS</td>
<td>70 YEARS</td>
<td>70 YEARS</td>
</tr>
<tr>
<td><strong>CONSTRUCTION SYSTEM</strong></td>
<td>200 YEARS</td>
<td>200 YEARS</td>
<td>200 YEARS</td>
<td>200 YEARS</td>
</tr>
<tr>
<td><strong>COMMUNITIES</strong></td>
<td>50 YEARS</td>
<td>50 YEARS</td>
<td>50 YEARS</td>
<td>50 YEARS</td>
</tr>
<tr>
<td><strong>HI BUILDING</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>MODULAR SYSTEM</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>RESIDENTIAL</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>MUSEUM</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

**THE PRESENT SHOWS THAT A LARGE MODULAR COMPONENT HAS MANY CONNECTIONS BECAUSE THEY ARE LESS ALREADY BUILT IN PlACES (HAVE A HIGH ENOUGH MASS, DON’T NEED DIFFERENT SYSTEMS FOR CONNECTIONS ETC.), SO FOR A EXPERIMENTAL STRUCTURE THE IDEAL CONNECTION IS JUST IN FORM AND ENERGIZE, NOT STRUCTURAL.**

**CHECK THE PERFORMANCE AND SCALABILITY BUT NOT A MODULAR BUILDING.**

**THEIR ACTIVITY SYSTEMS ARE LARGE, COMBINED WITH A SMALL TRAILER, LIKE DEPARTMENT 4 HAS MORE SIMILARITIES WITH A TRAILER OR MOBILE HOME THAN A BUILDING.**

**FUNCTIONS AND BUILDINGS DON’T NEED SPECIFIC SYSTEMS OFTEN BECAUSE THEY STRENGTHEN OTHERS LARGE BUILDINGS.**

**THEY ACTUALLY BROADEN BUT THEY SUFFER FROM DELAYS ANY CHANGES IN ITS FORM OF THE BUILDING IS SHOWN BY ITSELF WITHOUT ANY CHANGES IN THE BUILDING AT 150 YEARS.**

**SMART CONSTRUCTION SYSTEMS ARE CONSTRUCTION SYSTEMS TO INTEGRATE IN THE SYSTEM SO IT’S FULL POTENTIAL IS EXPLOITED.**

**THE SEPARATION IS INTEGRATED CONSTRUCTION SYSTEMS TO INTEGRATE IN THE SYSTEMS TO PREVENT THE DEVELOPMENT OF THE BUILDING ON THE TWO AS BECOME DISTINCT.**

**THE SYSTEMS ARE A GOOD EXAMPLE OF AN INTEGRATED MODULAR SYSTEM.**

**IT COMBINES CONSTRUCTION WITH THE FACADE AND MATCHES THE TECHNICAL LIFECYCLES OF THE SYSTEMS.**
<table>
<thead>
<tr>
<th>PERFORMANCE</th>
<th>TECHNICAL</th>
<th>ECONOMICS</th>
<th>ESTHETICS</th>
<th>CONCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUILDING PROGRAM</td>
<td>TECHNICAL LIFECYCLE</td>
<td>SCALE</td>
<td>CONNECTION</td>
<td>TIME SHORT</td>
</tr>
<tr>
<td>HOUSING</td>
<td>77 YEARS</td>
<td>BUILDING construction: 6-8 months; 3 days per module</td>
<td>High-quality materials; moderate investment</td>
<td>High</td>
</tr>
<tr>
<td>DRY HOUSE</td>
<td>TOTAL = 60 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMPORARY SPACES</td>
<td>1 YEAR</td>
<td>SPACE</td>
<td>High-quality construction; 3 days per module</td>
<td>High</td>
</tr>
<tr>
<td>PORTA KABIN</td>
<td>TOTAL = 60 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSTRUCTION</td>
<td>1 YEAR</td>
<td>WALL</td>
<td>High-quality materials; 3 days per module</td>
<td>High</td>
</tr>
<tr>
<td>CAMILY</td>
<td>TOTAL = 50 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOUSING</td>
<td>77 YEARS</td>
<td>SPACE/BUILDING</td>
<td>High-quality materials; 3 days per module</td>
<td>High</td>
</tr>
<tr>
<td>SYSTEM 2</td>
<td>TOTAL = 50 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOUSING</td>
<td>77 YEARS</td>
<td>WALL</td>
<td>High-quality materials; 3 days per module</td>
<td>High</td>
</tr>
<tr>
<td>CHILD PLAN</td>
<td>TOTAL = 60 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUILDING</td>
<td>40 YEARS</td>
<td>WALL</td>
<td>High-quality materials; 3 days per module</td>
<td>High</td>
</tr>
<tr>
<td>BLENK</td>
<td>TOTAL = 50 YEARS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Estimated technical lifespans of building components based on actual lifespan [derived from observation piecewise LSET 6 ENERGIE DIA 1574 of construction quality and material usage].

Repositionable modular buildings
2.5 IN DEPTH ANALYSIS

In this part of the paper four case studies will be closer examined, especially on the modularity of the parts and/or the repositionable qualities of the building harbors.

The four case studies are:

- The nomadic museum
- System3
- Huf haus
- Portakabin

The examination will consist of the following six aspects of the building:

- Load bearing
- Stability
- Materials
- Connections
- Transport
- Installations

The six aspects describe how the specific building manages to be repositionable and/or modular, and what influences this performance has on the aspects. The lessons from the in-depth analysis could be useful to the repositionable modular art podium I am planning to design. In this way the qualities of the individual buildings will be transformed into guidelines or focus points to be integrated into the preliminary design.

Before the assessment on the aspects stated above a general description of the building and the specific reason behind their choice will be described.
2.5.1 NOMADIC MUSEUM SHIGERU BAN

GENERAL DESCRIPTION

The Nomadic museum is a building that travels across the world to display the “Ashes and Snow” photography and film exhibition by Gregory Colbert. After its first assembly in March 2005 in New York the building moved to several places all over the world (Santa Monica; California; in 2006, Tokyo; in 2007 and Mexico City; in 2008). The walls of the museum are composed of 148 shipping containers. After the museums time in a city has ended 39 of these containers will be filled with the remaining building components and shipped to the next location.

REASON BEHIND CHOICE

As my ambition for the graduation project is to design a traveling art podium which can change its appearance in each city by its modular setup it would be logic to choose a precedent which does the same except changing its shape. In addition the building has a appealing appearance which, in my opinion, clearly communicates that it is a museum. It has some elements which bind the design together to be a whole instead of being several components bolted together as the majority of the modular buildings have.
LOAD BEARING

The exterior images give the impression that the roof of the building is supported by the two container walls on the sides and the columns in the center. But this image is deceiving, the central columns are a decorative reference to the first ‘Ashes and Snow’ exhibition in the Venice Arsenal in Italy as the bottom image on the right shows. The roof is supported by the two container walls only, with tension rods absorbing the horizontal forces.

STABILITY

On each of the connection points on the corners of the containers a truss is mounted which are connected to each other with girders and wind bracings. Because the containers are positioned in a checkered board pattern the horizontal forces can be directed straight down through the walls of the containers to two foundation poles. These foundations poles are screwed into the ground to ensure a level basis for the containers to be stacked.
MATERIALS

Shipping containers
The steel shipping containers used to move the museum serve as walls when the museum is deployed.

Aluminum trusses
These extruded tubes are connected to each other to form a 20 meter wide span. When disassembled the length of the members fits inside the containers to be shipped to the next city.

Roof membrane
Between the roof trusses a PVC membrane fabric is hung to give shelter to the museum. The inside of the fabric is painted black to be non reflective and, in combination with the careful placing of spots, give an itemed atmosphere to the exhibition.

Columns
The columns are made from cardboard and can be divided into sections to be transported in the shipping containers.

CONNECTIONS

Twistlock
The containers are connected to each other with twist locks. This fastening system is a common sight on trailers and ship docks to secure containers. The device consists of a rectangular steel bolt which can turn 90 degrees when a container corner connection is placed on top of it. By doing so the container is locked on all three axes.

Bolt
The aluminum frame which holds the roof fabric in place is connected with bolds and rod tensioners to steel cables stabilizing the roof structure.

Lock pin
The girders are secured with lock pins. These metal bolts have no thread but are fastened with a metal ring preventing the bolt from falling out.
TRANSPORT

As explained before the structure can be shipped by 39 shipping containers all over the world. As shipping containers are used every day to travel the world it is needless to say this thought of packing the museum down to manageable shipping containers is a very clever plan.

<table>
<thead>
<tr>
<th></th>
<th>STANDARD 20'</th>
<th>STANDARD 40'</th>
<th>High 40'</th>
<th>40' pallet wide</th>
<th>40' high cube pallet wide</th>
<th>45' high cube pallet wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSIDE LENGTH</td>
<td>5.89 m</td>
<td>12.01 m</td>
<td>12.01 m</td>
<td>12.05 m</td>
<td>12.05 m</td>
<td>13.55 m</td>
</tr>
<tr>
<td>INSIDE WIDTH</td>
<td>2.33 m</td>
<td>2.33 m</td>
<td>2.33 m</td>
<td>2.42 m</td>
<td>2.42 m</td>
<td>2.44 m</td>
</tr>
<tr>
<td>INSIDE HEIGHT</td>
<td>2.38 m</td>
<td>2.38 m</td>
<td>2.69 m</td>
<td>2.28 m</td>
<td>2.28 m</td>
<td>2.70 m</td>
</tr>
<tr>
<td>DOOR WIDTH</td>
<td>2.33 m</td>
<td>2.33 m</td>
<td>2.33 m</td>
<td>2.42 m</td>
<td>2.42 m</td>
<td>2.42 m</td>
</tr>
<tr>
<td>DOOR HEIGHT</td>
<td>2.28 m</td>
<td>2.28 m</td>
<td>2.56 m</td>
<td>2.27 m</td>
<td>2.27 m</td>
<td>2.59 m</td>
</tr>
<tr>
<td>CAPACITY</td>
<td>33.18 m³</td>
<td>67.67 m³</td>
<td>76.28 m³</td>
<td>70.8 m³</td>
<td>78.7 m³</td>
<td>89.2 m³</td>
</tr>
<tr>
<td>TARE WEIGHT</td>
<td>2,229 kg</td>
<td>3,701 kg</td>
<td>3,968 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. CARGO</td>
<td>21,727 kg</td>
<td>26,780 kg</td>
<td>26,512 kg</td>
<td>26,600 kg</td>
<td>26,600 kg</td>
<td>29,270 kg</td>
</tr>
</tbody>
</table>

Schematic on the different shipping container sizes (http://www.oceancoiner.com/container%20sizes.pdf accessed dd. 2006-2012)

INSTALLATIONS

The museum, with its dimensions of 20 by 200 m, can be considered as a big structure. Yet it delivers the same protection from the elements as a tent or pavilion would do. There is no conventional heating or cooling system installed (maybe a portable heating cannon). The only installations found inside are electrical wiring for lighting. The actual electrical wires are not integrated into the building as this would be done traditionally. In fact it has more resemblance with festival lightning equipment meaning a lot of lose cables taped together to maintain some kind of order.
2.5.2 SYSTEM 3

OSKAR LEO KAUFMANN AND ALBERT RÜF/ KFN SYSTEMS

GENERAL DESCRIPTION

The Austrian architects Kaufmann and Rüf have been pursuing the single unit dwellings for quite some years resulting in the request from the Museum of modern art in New York to build a modular dwelling for the ‘home delivery’ exhibition in 2008. The structure is composed of several wooden boxes which can be connected to each other. The boxes are divided in two space types: a “serving” space (red in image 2.5.2 02) and a “naked” space. The serving space consists of a completely prefabricated unit which houses all the installations, staircases, kitchen, bathroom, etc. The naked space is bound by the floor, walls and roof of the wooden box. The interior is only defined in furniture chosen by the inhabitant.

REASON BEHIND CHOICE

By its smart programatic differentiation of “serving” and “naked” space the building can be packed very fast in a container sized unit.

Modular rectangular boxes can be connected to other boxes but it seems that these boxes consist of modular parts themself. In this way modularity will not be fixed to a specific scale but can be experienced throughout different scales making it also more adaptable on different scales.
LOAD BEARING

The construction of the building consists of massive laminated wooden panels. These panels take up all the loads of the building's weight and variable loads caused by the usage of inhabitants. The solid slabs of unpainted wood are produced without any holes for window frames, doors, etc. After the glue between the wooden parts has dried a CNC cutter will create all the necessary holes. In this way each 12 cm thick panel can be unique.

STABILITY

As explained before the massive wooden walls, roof and floor will act as the load bearing structure. The stability of the structure will be facilitated by the serving space. As this pre-constructed part of the building has more internal walls then the naked space it can direct wind loads from different directions down to the foundations. The architects argue that the boxes could be layered on top of each other (see image on the right) to create a multi-story building of ± 10 floors. In that case the serving spaces should be stacked on top of each other to generate enough stability.

As this is a hypothesis some questions rise on the feasibility of the plan. Would a 10 floor high building without a lift be functional? Are the 12 cm wooden panels at the base of the structure strong enough to direct the forces of the floors above? Do the modules at the top have the same dimensions of the modules at the bottom?

MATERIAL

Laminated wood
The walls, roof and floor are all made from laminated wood which is processed with a CNC cutter to create the holes for the window fittings. The idea of the architects is that the dimensions of the windows can be influenced by the climate of the future building site, so in high solar radiation loads smaller windows and vice versa.
Glass
The glass in the façade is held by a very minimally dimensioned stainless steel window frame. All the fitting is done in the factory under controlled conditions.

Stainless steel
Within the serving unit all elements are made out of stainless steel such as the kitchen sink, shower, toilet, etc. By observing these items the question rises if the layout of the building should be perceived as a real suggestion towards the functioning of the building (meaning this layout would be the one the customers will get when they purchase this building), or that this is somewhat of an conceptual layout suggesting where different functions would be placed. In both cases the current layout of “clean” stainless steel items confuses the visitor and gives the perception of a “unrealistic” structure.

CONNECTIONS

Below (image 2.5.2.05), the connections between the different exterior walls are shown (based on pictures as detailed drawings are not available). On the left the connection between the serving space unit and the naked space wall is shown. On the right the corner connection which can also be seen at the photo on the far right.

Repositionable modular buildings
TRANSPORT

As the building was manufactured in Austria transport to New York would take a great deal of planning if the building could not be reduced to the size System3 can.

Dimensions
System3’s external dimensions are 5.8 m x 11.6 m in its deployed state. Despite its modest size it manages to be transported in one standard shipping container (of 2.4 m by 13.5 m). As explained before the spaces in the building are divided in naked space and serving space. The naked space walls are delivered as separate panels to be assembled on site (see image 2.5.2.09 on the right). The idea of packing one unit with all the “difficult”, or “serving” as they call it, functions and making this box a fixed component reduces the amount of difficult connections which would be needed when the installations where mounted on different parts.

Weight
The actual weight of the structure is not documented in the available literature but due to the fact that it was shipped in one container the total weight of the building should be less than 29,270 kg as this is the maximum carrying capacity of a shipping container.

INSTALLATIONS

The concept of System3 is that all serving utilities are placed inside the serving space, especially the installations as these would become more and more complex as they would need to be assembled on site.

Heating and cooling
The placement of the heating and cooling installation is assigned to the serving space but how it actually heats and cools the building is not clear. No floor heating or radiators can be found in any of the published documents (this would also be inconsistent with their concept of naked and serving space) so the only option left is air heating and cooling by an air treatment unit.
**Electrical equipment**
Even all electrical wiring and other appliances are moved inside the serving space. Lighting in the naked space is acquired by a light bulb hung from the ceiling and connected with an electrical wire to a power supply in the serving space (see image 2.5.2 11).

**Fresh water supply**
This is facilitated in the serving space. As are the waste lines from the toilet, shower and kitchen sink.

**Rainwater drainage**
In the published literature there is no sign of rainwater drainage. Also the photographs taken from the roof indicate no drainage (shown on image 2.5.2 12). The architects state in the writings on the structure that the building shown at the MoMA is the smallest configuration possible. In their visions several of these modules could be stacked to create a tower. Keeping this tower in mind the presented (small) module could be seen as an in-between floor where the roof of one module is the floor of the one above, leaving a rainwater drain unnecessary. Nevertheless the neglecting of this topic contributes to the conceptual appearance of the building as mentioned before.
2.5.3  HUF HAUS

GENERAL DESCRIPTION

“HUF HAUS is a building company which is dedicated for more than 40 years to build prefab buildings. The buildings are characterized by the use of wood and glass in an architectural style which is somewhat reminiscent to the typology of the Swiss chalet. The company is specialized in turn-key completion which means the customer is not bothered with the procedures of building, selecting contractors, permits, etc. the company takes care of the whole building process. To achieve the precision, speed and quality the high end customers demand the company uses: a modular grid and prefabrication of the parts in a controlled environment.” (http://www.huf-haus.com; accessed d.d. 11-6-2012)

REASON BEHIND CHOICE

Nearly 100% of the building is constructed off site in a factory where more of these houses are produced which brings higher efficiency and reliability towards the customers. The consequence of the short building time is that large modules are constructed off-site, transported to the location and assembled on-site including the difficult and high performance connections between the modules (which have to be: water tight, sound proof, have enough heat resistance, etc.). Investigating on these connections could give some insight in the points of attention regarding the detailing of a building which consists of parts.
LOAD BEARING

As the image on the right shows it seems that the main construction of the HUF haus consists of laminated wooden beams and columns. But if we look closely to the details below we see that the laminated columns are not solid wood but have steel profiles hidden inside. Why this has been done has many explanations but the main reason is the integration of window frame, load baring column and the position for the connection between two panels. This solution is esthetically appealing but puts pressure on the column because this load baring element is now more than just a column and has to deal with the demands of the glass (being able to be mounted in a different construction phase) and the connection (being separable in two part which can be connected in a invisible way). These demands push the load baring properties to a small area where they can not be transferred to the foundations by laminated wood but need a stronger material, in this case steel.

In contrast with the columns are the roof beams which are totally made of laminated wood and not reinforced with steel. This because the beam does not have to perform the variety of tasks the column has.

Besides the columns and beams there is another structural element and this is the load bearing wall. This element is placed between columns and beams to provide stability to the structure and is also made from laminated wood.
STABILITY

Below the floor plans of a typical HUF haus are shown, in red the stability walls. The strength of the HUF haus system is its flexibility in construction elements. As can be seen in the floor plan the whole building is placed on a grid. This creates columns, beams and walls of the same dimensions which can be efficiently produced inside the company’s factory. In the design phase when the customer states his demands the company’s designer can rearrange the system until the demands are integrated into the design. On this way HUF haus can guarantee a short building time and high quality because they already built all of the components before, experienced the difficulties and solved these.
MATERIALS

As said before the materials used are not only wood and glass. Besides these materials: steel, insulation, concrete and gypsum integrated in the building. Below a short explanation how the materials are exactly used.

Wood
The laminated wood is the only ‘structural’ material which can be observed from the outside. Besides the esthetical aspects which are observed from the outside the laminated wood has another advantage. The laminating manufacturing procedure ensures the quality of the wood which makes calculations (on the fields of structural integrity, fire protection and thermal insulation) more precise. These calculations on their turn provide a stable basis for more elegant detailing. Besides the qualities mentioned above wood can also be easily shaped into the desired form which makes modular connections possible.

Glass
The glass used in the HUF haus is High efficiency glass which is common in new buildings. As the detail on the right (image 2.5.3 10) shows the glass is fitted from the inside after the module is placed on-site. A wooden covering plate locks the glass in position.

Steel
As mentioned before the steel inside the wooden columns guarantees the actual load bearing properties of the building but at the same time provides a stable platform for the other parts of the module. As wood expands and contracts under the influence of temperature and moisture levels the dimensions of the parts can not be exactly determent. To counteract these variations in dimensions large tolerances in the connections should be introduced but this would affect the esthetics of the building. The steel frame used inside the modules prevents the module from expanding or contracting too much and prevents the need for large tolerances in the connections.

Insulation
Although the insulating capacities of the laminated wood are higher than other building materials like steel or concrete this is not enough to ensure an adequate heat resistance. This thermal insulation is reached by covering the outside of the laminated wooden walls with a layer of insulation covered with a cladding (wood or plaster). As almost every material in the HUF haus the insulation is integrated in the part and the parts are assembled on-site.
Concrete
The floors of the HUF haus are made of precast concrete elements which can be quickly assembled on-site and have acoustical properties which dampen the sounds from one room to the other.

CONNECTIONS

The connections of the HUF haus are designed to be assembled or disassembled one or two times. This statement is based on the screws which connect the parts. As can be seen on the detail to the right the roof part is connected with the facade part with a screw which drills itself into the wood. When this connection would be undone the parts would come loose but the wood is left behind damaged. Over time the wood gets more and more damaged each time a connection is made resulting in a more and more unstable connection.

TRANSPOST

The parts of the HUF haus are transported by special trucks owned by the company. In this way the largest possible parts can be produced which still fit on a truck. Over the years HUF haus also built 4 houses in China. These were transported with a shipping container by freighter. As the parts are designed to fit on a flatbed truck the shipping container is too small to harbor the parts. This problem is solved by removing the roof of the container and construct a temporary enlargement on top of the container (see image 2.5.3 13).

(INSTALLATIONS

The HUF haus can be made weatherproof within one week after the start of the first part has arrived on-site. Installing the floor heating, electricity and water pipes takes a more time. As these components are not prefabricated in the large scale of the building parts they have to be assembled by skilled workers on-site.)
2.5.4 PORTAKABIN

GENERAL DESCRIPTION

Portakabin manufactures and delivers modular buildings to clients which have a temporal need for space. By controlling every aspect between the building of the modules and adapting them to the customer’s specific needs they can ensure on time and on budget delivery. The majority of the clients which use Portakabin buildings are schools and companies which suddenly need more space on a specific place, for example due to the renovation of the main school building or the acquiring of a large assignment so the company needs to grow rapidly to enlarge its capacity. These clients use Portakabin to solve their temporal space shortage to buy time for the development of a structural solution, the average renting time is 2/3 years.

REASON BEHIND CHOICE

The interesting idea behind Portakabin is that they try to satisfy the different needs of their customers but at the same time try to fit it in a system which demands repetition and order. Next to this architectural problem there are some technical problems which have to be solved. How do you join modules but ensure a satisfying indoor climate? How do you heat and cool your building? How is the electrical system wired together without refitting the total system every time?
LOAD BEARING

Portakabin has several systems to provide customers with temporary space but in this analysis we will focus on the “ultima” system. This system consists of several modules which can be connected to each other to form different building volumes.

The construction of the main module, as depicted in image 2.5.4.07, is composed out of four (350 x 120 mm) cold formed steel profiles together with four (120 x 120 mm) columns. The floor of the module is supported by cold formed steel profiles (160 x 60 mm) with a centre to centre distance of 400 mm.

When several modules are connected together they are bolted to each other to ensure a stable connection. The bolts are located at the top U channel profile.

The foundation of the modules is site specific and needs at least four corner supports which are level and preferably two extra supports in the middle of the modules long side.

STABILITY

The stability of the structure is provided by the sandwich panels between the columns. They are bolted at regular intervals and consist out of: a coated metal outer layer, foam insulation in between and an inner layer of 12.5 mm gypsum board. Because the wall panels act as stability-walls the openings in these walls can not be too big and can not be removed. In the image below (2.5.4.04) these stability walls are depicted in blue, the green flooring (chip board connected to the girders below) act as horizontal stability elements.
MATERIALS

The Portakabin modules are composed from several materials. Below a list of the main elements is shown together with their main function.

Steel
As indicated before the main construction is made from warm rolled and cold formed steel. This material can transfer high loads in comparison to its weight and can be easily connected trough welding or bolting to other parts.

Wood
The wood used in the sandwich panels serves two functions. The first is to act as battens between the metal outer layer and the gypsum inner layer. In this way some space is left between the two layers which can be filled with insulation. The second function is the ability to repeatedly secure screws into the wood on different places.

Insulation
Also the insulation serves two functions. The first is of course to insulate the building preventing a high heat flow between inside and outside. The second is providing stability to the whole structure. Ones the batty has created the cavity space this is then filled with liquid foam insulation which hardens inside the cavity. This will enhance the shear force resistance of the panel providing a stable element for the building to deflect wind forces towards the foundations.

Gypsum
The inside finishing of the walls and ceiling is made from gypsum board to prevent fire from spreading, reduce resonance sounds inside and give a nice interior finish.
CONNECTIONS

The connections between the modules might seem like a complicated piece of engineering but are in fact surprisingly simple. Apart from the bots described earlier in the text some expanding tape is used to seal the small gaps between the modules. The roof connection has a special cap which shields the gap from direct water contact as the detail to the below shows (image 2.5.4 11).

TRANSPORT

The dimensions of the modules are larger than the maximum transportable volumes a flatbed truck may transport without being designated an ‘oversized’ load. This means the transportation of the modules requires special attention.

INSTALLATIONS

Electrical
To provide electricity to each module without rewiring the whole electrical system each time every module has its own fuse box from which power is distributed throughout the module. When the modules are connected together the fuse boxes are connected one after the other with a maximum of 6 units. The advantage of this system is that it does not matter where the power enters the building as long as it reaches one fuse box.
**Heating and cooling**
Heating and cooling is arranged in a similar way the electrical system is. Each module has a heating device mounted to a wall. If multiple rooms are fitted inside one module several heating devices could be mounted in each room. As the heating device works on electricity the place and amount of the heating devices don’t matter that much.
Cooling is a bit more complicated. The cooling unit needs to be connected to an outer wall to discharge warm air. This need to puncture the outer wall prevents the unit from being moved.

**Lighting**
The lighting system is connected to the electrical system but not controlled by it as it normally does through a switch wire. Instead a remote control device switches the light on and off. The reason this is done comes from the flexible floor plan the modules have. Inside the modules separation walls could be placed anywhere, this means the fixed lighting would need to be rewired every time the room’s dimensions are changed. This time consuming job is now replaced by resetting the remote control units and reassigning them to which switch they should respond.

**Ventilation**
The ventilation need for the rooms is provided by a centralized mechanized supply duct. This over-pressure inside the building prevents cold air from outside from entering the building through an unfortunate hole.

**Water**
The water supply is custom made because water is not always needed in each module (imagine toilets, sink, kitchenettes etc.). After the renting period is over the company tries to incorporate the ‘customized’ module to a new client.
3.0 CONCLUSIONS TECHNICAL RESEARCH

- Transport

Large and heavy objects can be moved with relative ease over small distances (e.g. a crane lifting and moving a heavy object over 50 meters). It becomes more difficult when the transport needs infrastructure to move the load from location A to location B. For a few kilometers with little obstacles it is possible to use the road to transport very large objects (as shown in image 3.01). But when larger distances should be covert the parts should adapt to the maximum transport sizes depending on which transport type is used (containership, truck, train, etc).

The consequences of this statement are the determination of an action radius for the transported building parts. It makes a huge difference if the building parts can be transported by truck only and therefore are limited to maximum transport sizes for trucks in comparison to movement by ship where all parts should fit inside a container which dimensions are considerable smaller.

- Connections

Connections can be made in infinite ways but choosing the right one to do the job is difficult. In the case of a repositionable building the connections are not permanently fixed like in a traditional building. They go through a repeated cycle of assembly, usage, disassembly and transport to break the building in movable parts and being able to move these parts. This demands other performances of the connections such as the ability to connect and disconnect, resistance to damage while transported, replacement of damaged parts, etc. These improvements have the ultimate goal to speed up the assembly and disassembly time but will also, in most cases, increas the costs of the connection.

The balancing between the following two aspects should be made. The increase in initial investment costs to produce the connection should be covered by a gain in assembly time multiplied by the number of cycles the connection is assembled and disassembled.
- **Weight**

The weight of a unit should be kept to a minimum. This will reduce transport costs due to lighter equipment (trucks, cranes, etc) needed for transportation and lifting. Besides this the reduced weight will also lower the total weight of the building which will decrease the need for heavy foundations. Finally, the reduced weight of the units will lower the forces the bottom unit needs to transfer to the foundations when multiple units are stacked on top of each other.

- **Scale**

Increasing the scale of a unit will result in fewer units necessary to build the same building volume and thereby reducing the number of connections in the total building which will ultimately speed up assembly/ disassembly time.

- **Batch size**

An increase in batch size will lower the costs per unit because the initial startup and research costs can be divided over all units produced. This statement can also be reversed. If you design a highly complex object which has high startup costs (research), be sure to use it as often as you can to reduce the average costs of the objects.
4.0 DESIGN

4.1 STARTING POINTS

As can be read in the first pages of the report there are two main starting points which describe the goal of the project. I will repeat them below.

1 Movement
As the Art Podium will serve multiple cities over the years the movement from one place to another should be as efficient as possible to reduce the energy needed for each transition.

2 Adaption to context
While the Art Podium changes location over the years, an adaptation to the local context should be made. In this way the Art Podium can serve new locations better compared to a relocating building which could only be assembled in exactly the same way each time.
4.2 IMPLEMENTING TECHNICAL RESEARCH IN DESIGN

With the conclusions drawn from the technical research we are now able to design the Repositionable Art Podium for The Netherlands. Below the main conclusions are stated with an explanation of the consequences of these conclusions for the Art Podium.

Transport, Scale and Batch size

The goal of the Art Podium is to travel from one city in the Netherlands to the other adapting itself to new surroundings as it goes. This means the building components should be within the limits different transport systems can support (air shipping, train, truck, boat). After analyzing these kinds of transports I came to the conclusion that whatever transport is used a truck is always needed to move the building components the last few kilometers. Besides this fact, the Netherlands is a relatively small country which makes transport by truck throughout the whole country economically feasible. By studying the transportation limits for trucks composed by the Dutch government images (4.2 02 and 4.2 03) presents an overview of different kinds of truck combinations allowed on the road.

The most interesting image was transport combination C which shows two equal volumes pulled by one truck. These equal volumes could answer to another conclusion from the technical research namely: “enlarging batch size reduces costs per unit”. From this transport combination C we can deduce the maximum size of the individual building volumes which is stated below. These maximum dimensions also limit the scale of the unit, as building parts cannot be bigger than the volume stated above.

TRANSPORT LIMITS DUTCH ROADS
(lowest convoy exceptional class)

- Maximum height: 4.0 meters
- Maximum length: 27.5 meters
- Maximum width: 3.5 meters
- Maximum weight: 100 tons
Connections

As the units can be easily transported by truck the “loading time”, or time it takes for the unit to be disassembled from the overall building should be several minutes. In this way the total relocation of the Art Podium to a new city doesn’t take more than two weeks.

Keeping this thought in our head the main performance of the connection between units should be assembly speed. To design the connection needed between the units (which will be explained later) I looked at scaffolding connections and the way they can be fixed in seconds with only a hammer. Another advantage they have is that when disassembled the connections has no lose parts which could get lost or damaged in transportation.

Minimal weight

To reduce the weight of the units, materials should not be selected only by their mechanical, insulating or toughness properties but also assessed by their weight. While searching for possible solutions sandwich panels came into view because they use materials with high strength on the two outsides of the panels where the majority of the loads is transferred and lighter material on the inside where the forces are lower. This system has another advantage besides being efficient in weight versus the loads it can carry but also could serve as an insulation barrier between the inside and outside. This thought of combining functions in one element could be further exploited by incorporating other functions into the element like: electrical wiring, interior finishing, exterior cladding, etc and in this way producing an element which uses as little material (weight) as possible where the different functions could benefit from each other.
4.3 DESIGN OF THE MODULES

As explained before there are several technical conclusions that point to the development of as large as possible building volumes with high batch numbers so the production costs will be lower. When only these conclusions are implemented in the design the outcome would be a building composed out of several units which are exactly the same which maybe could adapt its form to a new surrounding but could it do the same with room sizes? And if it could do this transformation in room sizes is it still one unit or is it on its turn composed out of several elements which can be rearranged? Is an art podium with all the same room sizes of +/- 3 meters wide, 9 meters long and 3 meters high (deduced from the maximum transportable volume) usable?

The questions above are some of the countless questions designers ask themselves in the design process but the only thing that matters is the end result which can be judged as a whole. How well does the building perform on all aspects together (technical, functional, esthetical, economical)? In the next pages the final design will be presented where sometimes the considerations will be explained but not every single one will be elaborated on.

Module types

To create the largest possible module but still have diversity in the sizes of rooms the following types of modules are developed (depicted in image 4.3.02) which together can be assembled on countless ways to produce rooms with different sizes for different functions (e.g. staircase, exposition hall, entrance hall, etc)
Combinations

As shown in the image 4.3 03 types A, B and C can be combined to create rooms of 2.6 meters in height. Types D and E can be used to form double high rooms of 5.9 meters.

Expansion

Thanks to the load baring system inside each module, the room can be expanded next to each other with types C and E. In this way the size of the rooms can be modified towards the need of the user.

Rotation

The modules are designed so they can be placed on every flat surface. This means floor can be roof can be wall. The advantage this gives works in two ways:
- The rotation of the modules gives more variety to the possible room configurations
- By the rotation of the modules the location of the connection holes can be manipulated without modifying the modules or introducing more types. In this way the disassembly of the building is used to rearrange the connection holes.

Image 4.303 schematic on the possible combination methods

Image 4.304 images explaining how the place of the connection holes can be manipulated
Infill

The connection holes can be covered by various infills depending on the function of the hole. When the connection hole faces outwards a door or window infill can be placed. If the connection hole faces to the ground or against another module a closed infill can be placed. When two modules are placed next to each other and their connection holes align a connection infill can be placed to provide a weatherproof connection between the spaces inside the modules.

Generic versus Specific

The modules explained until now only provide generic spaces which can be easily assembled/disassembled and transported. These generic spaces facilitate rooms which are climatised, weatherproof, have daylight illuminating the interior and provide electric sockets for equipment but don’t serve a specific function (for example an entrance hall or exhibition space).

To make the specific function possible the room has to be equipped with furniture which is dedicated to the function. For example: when you take an empty room and you attach an art object to the wall the room will become an exhibition space. If the room should be an entrance hall, drive in a counter to sell the tickets and some chairs for waiting and it is an entrance hall.

Summarized, the module provides a certain level of essential qualities every room needs (like a stable climate, weatherproof, etc), the specific function of the room is stated by the objects/furniture the user put inside.

<table>
<thead>
<tr>
<th>generic rooms</th>
<th>specific function</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&quot;the stem cell&quot;/ &quot;basic module&quot;)</td>
<td>- The arrangement which makes specific use possible (stairs, furniture etc)</td>
</tr>
<tr>
<td>- different room shapes</td>
<td>- artificial lighting</td>
</tr>
<tr>
<td>- climatised interior</td>
<td>- treatment of daylight</td>
</tr>
<tr>
<td>- providing daylight access</td>
<td>(exclude, pass through, weaken)</td>
</tr>
<tr>
<td>- harbor construction</td>
<td></td>
</tr>
<tr>
<td>- weatherproof</td>
<td></td>
</tr>
<tr>
<td>- electrical systems</td>
<td></td>
</tr>
</tbody>
</table>

image 4.306 different infills which can be placed inside the connection holes

image 4.307 different infills placed inside the connection holes of the modules
Specific layout

The reason why I chose for the strict separation between generic module and specific infill are the ever-changing art exhibitions which should be harbored inside the modules. I can not imagine what the next exhibition is about, let alone decide how it should look like. These decisions should be made by the curator of the Art Podium (the user) and he should be given the tools to do so.

Below a list of “tools” are described which can be influenced by “the user”

Daylight

Daylight and art have different relationships depending on the kind of art. For example: paintings do not want reflection from direct sunlight, cinematic art wants no light or little light, etc. As these requirements depend on the art placed inside the module the user should determine which kind of daylight should enter the room. To influence these light qualities the window frames have the option to put in different kinds of daylight manipulating infills. These rectangular frames can be made from any material of the same dimensions, can be easily mounted inside the window frames for rapid substitution and should be made from low cost materials if they are used only once.

Room size

As mentioned earlier in this paper the modules can be configured and rotated in numerous ways to derive various room sizes which can be adjusted to the art which is placed inside. Below several options are shown.
Interior finishing

The whole interior surface is covered with wooden multiplex boards (25 mm thick) which has two functions. The first is to act as roof, floor or wall finishing depending on the configuration of the modules. The multiplex has enough strength to withstand the wearing a floor is put through but can also be easily repaired or painted when damaged. Another function the multiplex fulfills is the protection of the (structural) composite which is behind it. While the composite is sensitive to damage from attaching objects to its surface (especially screwing) the multiplex is not and acts as a buffer between the users (who occasionally wants to attach furniture, artificial lighting, art, etc to the wall) and the composite. When the multiplex is heavily damaged beyond repaired a new (thinner) layer of 5 mm multiplex can be screwed on top of the old one or the whole existing interior can be refurbished with a new layer of 25 mm thick multiplex.

Multifunctional layout

The geometry of the rooms inside the modules is a plain rectangular shape to provide optimal support to different floor plan layouts placed inside. Within this rectangular shape no objects which belong to the module (e.g. construction parts, electrical sockets or cover plates) may cross the boundary of this rectangular shape. As a wall could become ceiling or floor the surface should be flat and free of any obstacles where visitors could stumble across.
4.4 TECHNICAL ELABORATION

4.4.1 FABRICATION

As explained before the building consists out of 5 types of modules. These modules differ from each other in the way walls are placed and connection holes are positioned but, they still answer to the same measurement grid of 3.33m height, 3.33m wide and 9.99m long. These similarities make the fabrication setup of the modules very alike.

Below a step by step fabrication description is given for module B.

First a steel grid is constructed to provide structural stability and guide vertical forces to the next module below or the foundations.

Between this frame a composed layer of high density foam to insulating the module (300 x 300 mm) glued together with strips of composite material (11 mm thick) which guide the floor/ wall/ roof loads to the steel frame. The composed layer (which is just a rectangular block when glued together) will be formed by an automated 5 axial milling machine (image 4.4.1 02) to produce the necessary shapes required to fit each piece between the frame. Next to the precision forming of the composed layer (which will have multiple functions e.g. load carrying, insulating, harboring electrical wires and providing a slope for rainwater) the automated system has another advantage namely the
repetition of several modules (about 20 of each type) which make the average costs of the modules cheaper due to a more efficient manufacturing process which comes by a larger batch size.

When all the composed panels are in place the electrical wiring will be installed and the whole module will be covered with a layer of fiberglass composite which provides a protective layer to shield the interior from rain and wind, provides stability to the steel frame by absorbing vertical forces. The method used for applying this layer of fiberglass is called spray-up method and can be done manually of by a robot depending on the economical efficiency of eater system by the given batch size.

Next, the rainwater gutters are glued into place which also serve as the attaching/reference points for the facade panels. In the detail to the right a final cross section is shown depicting the different layer and their functions.
In the next phase the facade panels are mounted and are made from solid composite plates (3.33m by 9.99m) formed by a mall under pressure. The advantages of this system is that the facade is a continuous plate with little chance of leakage by construction faults and it can be mass produced as all sides of the module have the same facade plate (except the two end walls). The groves in the facade plate guide the rainwater to the edges of the module where larger gutters take it to the corners and then down to the next module or ground connection.

The last step in completing the module is the attachment of the interior finishing. The multiplex could also be precut by automated laser cutters or electrical sawing tables which makes mounting them inside de module like putting together an IKEA closet.

When all the interior panels are placed final mounting of electrical sockets, connections for auxiliary construction and infills for the connection holes can be done.

On the next page several details are shown depicting various options for possible infills like: windows, doors, connection or closed infills.
image 4.4.16  detail on two modules connected to each other where one modules connection hole has a closed infill

image 4.4.17  detail on two modules connected to each other where one modules connection hole has a connection infill

image 4.4.18  detail on two modules connected to each other where one modules connection hole has a door infill

image 4.4.19  detail on two modules connected to each other where one modules connection hole has a window infill
4.4.2 CONSTRUCTION

How the modules can be used (stacking, overhang, span) largely depends on the mechanical properties of the modules and they're connection to each other. To simulate this, a computer model is created to study the mechanical performance of the modules. In the next pages different combinations are simulated to find the limits in height of stacking, length of overhang and length of spans.

In the image below (4.4.2 03) a model of module A is shown. The yellow bars represent rectangular hollow sections of 100 x 100 x 8 mm and the purple bars represent additional reinforcements (2 rectangular plates of 310 x 5 mm) to allow forces to travel around the connection holes without causing extensive bending moments in the profiles. The composite inner and outer layers which provide stability and transfer horizontal forces to the module are simplified by cables for practical reasons.
Overhang

In the image 4.4.2 04 module A is positioned in an overhang situation which is explained in the static diagram (image 4.4.2 05). For the live loads a force of 3.75 kN/m² (2.5 kN load x 1.5 safety factor) floor is maintained and the dead weight of the module is estimated on 120 kN total. Combined this results in a load of 210 kN which is evenly distributed over the model. The results show that by the given loads the deflection at the end of the model is about 18 mm. This is well within the margins of 80 mm which is stated below. Also the internal forces inside the profiles stays within the acceptable range of max 235 N/mm².

Because the forces and deflections are so well within range I conducted a second simulation of two modules connected end to end with an overhang of 20 m. Although the deflection still stayed in range the internal forces exceeded the maximum allowable strain by 2.5 times.

The conclusion regarding to overhangs is that a module can safely be put in an overhang position of 10 m.

![Diagram of the building module](image 4.4.2 05)

![Diagram of deformation and stresses](image 4.4.2 04)

![Diagram of maximum deflection calculation](image 4.4.2 06)
Span

In this simulation the same simplified model is used as the overhang situation except that they are connected end to end to form a span across two modules. The span itself consists of 3 A type modules spanning 16.65 m.

For the loads the same values as the previous example are used so the weight for each module (including live and dead load) is about 210 kN.

The results show, by the given span, a deflection which is well within rang and internal forces that just exceed the maximum strain levels.

The conclusion regarding to spans is that the modules can just make a span of 16.65m (or 5 grind lengths of 3.33m).

\[ U_{\text{mm}} = 0.004 \times l_{\text{crush}} = 0.004 \times 16.65 \text{ m} = 0.066 \text{ m} = 6.6 \text{ cm} \]
Stacking

In the last simulation several units are stacked on top of each other. In the image (4.4.2 10) 4 type D modules are connected together horizontally and 4 of these clusters are placed one on top of each other. For the wind loads, which have a greater influence in high structures, a value of 1.21 kN/m² is included in the calculation which represents the high wind loads that can be found at the coastal area in The Netherlands including safety factors. The results show slightly exceeding values for strain and deflection. After recalculation with only 3 clusters on top of each other the values lowered within tolerances.

The conclusion regarding to stacking is that the modules can be safely stacked 9 grind lengths high which is the equivalent of 29.97 m without additional supports.

\[ U_{\text{tot}} = \frac{h}{500} = 40 \text{ m} / 500 = 0.08 \text{ m} = 8 \text{ cm} \]
Landmark tower location “Scheveningen”

The tower for the location Scheveningen was also simulated to study the influence of the shifting exposition halls in relation to the route meandering upwards. The first results showed massive deflection in the tower (which can be seen in image 4.4.2 14 below). After structural analysis of the sections to the right the cause of these deflections are the absence of the red columns and bars. Without these reinforcements the forces need to travel a long and inefficient way towards the foundations causing massive deflections and bending moments in the process.
After correcting the structural model with de reinforcements the deflection stays within acceptable limits but the strain inside the profiles is still very high.
To solve these issues a more accurate model should be made where the connections between the “roof” bars and “wall” bars can be modeled pivoting so bending moments in the “roof” due to dead weight do not cause bending moments in the “walls” making them more vulnerable to buckling by vertical loads. Unfortunately this is a very time consuming job which is leaving the scope of my graduation project.
As the modules have connection points to connect module to module the same points can also be used to attach additional reinforcement structures. This ability makes the question of “can the tower be made?” irrelevant and replaces it with “how much additional reinforcement structures do we need to make the tower possible?”

\[
U_{\text{tot}} = \frac{h}{500} = \frac{30m}{500} = 0.06 \text{m} = 6 \text{cm}
\]
4.4.3 INSTALLATIONS

The last big technical hurdle (besides fabrication and construction) is installations. How do you heat, cool and ventilate a building which can be disassembled? And how do you guarantee that it works in different configurations? These questions I hope to clarify in the next pages starting with ventilation.

Ventilation

In the early explanations of the design at the beginning of this chapter I stated that various infills could be mounted inside the connection holes. These infills could be used to mount a window, door or connect to another module. But when neither of these infills can be used the hole needs to be covered with a closed part. This closed part (which occurs in almost every room) can also be used to harbor the installations for heating, cooling and ventilation. The principle works as depicted below. Between two rooms a small cavity of ± 40 mm is left which gives the installation infill access to fresh air. This fresh air will be forced inside the room by a ventilator inside the infill. This causes an overpressure to buildup inside the room. In the window infills, small ventilation grills are installed which can be opened and closed. In this way the user can influence where air exits the room and where it will be replaced by fresh air by the overpressure.

VENTILATION

COOLING
Cooling and Heating

The cooling and heating principle of the building works in similar ways as the ventilation system. The outside fresh air is treated inside the installation infill before it is propelled into the room. The reason why air heating is used instead of traditional floor or radiator heating is the complexity those system form when they need to be taken apart once a year. Imagine all the connection hoses that would be necessary to connect different modules to each other if they would use water for heating and cooling their floors. The installation infill only needs electrical power and can be easily unplugged and relocated to another connection hole who has become unused by the other infills in a new location.

As the warmed or cooled ventilation air is not enough to warm or cool the whole building the unit should also be able to draw and treat air from the inside to deliver enough output. When studying different heating and cooling techniques I noticed the difference in volume the machine occupies to produce the same heat or cold per square meter. This difference is also visible in heat or cold demand per square meter. The calculation to the right (image 4.4.3 03) tries to find a balance between the variables with the goal of a single installation unit which can cool and heat the same amount of square meters.

The result is to partition the installation unit to about 60% cooling and 40% heating which should cover the square meters by the given height as depicted in the table to the right (image 4.4.3 03).

HEATING
Electricity

Electricity is the only source of power which is delivered to each module and (as explained in the fabrication paragraph) is incorporated into the walls, roof and floor. These cables will lead from the connection holes to the small spaces where models are linked to each other. In this space an electrical connection can be made from one module to the next or to the outside to connect to the city grid as shown below. These small spaces could also be used as cable gutters so electrical wires can be drawn around the room to whatever position they are needed. As image 4.4.3.06 shows only the corners of the rooms are left uncover so on those spots electrical sockets should be placed to provide electrical power.
4.5 COMPOSITIONS

In this section the adaptation to a new context, which was point two from the starting points, will be explained by simulating the movement of the Art Podium to different locations throughout the Netherlands. To show the adaptation quality’s of the building different kinds of locations are used (city park, city square and open field).

The designs use almost the same number and types of modules used in the design for Scheveningen (the maximum deviation is 5% less than the in total 87 modules used in Scheveningen)

Vondelpark Amsterdam

The Vondelpark lies on walking distance to the centre of Amsterdam and is a landscaped city park with picturesque bridges, ponds and recreational grass fields. This open space in the center of the city provides a suitable location for the art podium to temporarily substitute, for example, the “stedelijk museum amsterdam” which as in through a large renovation for several years.

The design consists of two volumes where one is placed on the relatively small grass field besides a pond where the larger volume “hovers” over. In this way the building adapts to the small footprint provided by the location.
Vrijthof Maastricht

The Vrijthoff city square lies in the centre of Maastricht and is known for the numerous activities throughout the year like concerts, markets, etc. In this context the art podium should use very less volume to allow enough space for the other festivities on the square. The design consist of a cubic volume of 16,6 m high and 30 x 30 m ground square. The volume pierced by holes to bring daylight into the centre of the volume and to let visitors enter the building on the ground floor.
Goffertpark Nijmegen

The Goffertpark in Nijmegen is a vast park which harbors a football station and several festivals throughout the year. Space on the open grass fields is plenty and varied with woods. In this open field the Art Podium can interact more with the surroundings and maybe use the outside space as exhibition space to. In The design shown below this is exactly what the building does. On the left side is a closed volume with only inside spaces and when moving through the building to the right the spaces gradually become more and more outside where in the end the building is totally dissolved into exterior space.
4.6 LOCATION SCHEVENINGEN

For the location Scheveningen I chose the boulevard as a suitable spot for the Art Podium. Especially in summertime the boulevard is a crowded place where people seek recreation and may be susceptible for a visit to the Art Podium and meet the local artist community.

In the next pages the main design influences are explained followed by several floor plans, sections, and facade drawings.

![Diagram of Scheveningen location](image)
As can be seen on the previous page the Art Podium is situated on the beach between the main boulevard and the beach boulevard where it is one of many structures build along these recreational promenades. This idea of buildings along a main route was inspiration for me to give the Art Podium a clear internal route and bind the separate modules together to form one building or composition.

In the images to the right this initial route can be seen with larger exhibition halls placed on top of it. To increase the difference between the route and the exhibition halls they are placed with an offset (but still matching the structural grid of the modules) on top of each other.

To create a buffer zone between the potential visitors walking along the boulevard and the actual entrance of the Art Podium the route follows a U shape to define a place/square in the center. This square (where some large art installation could be placed) could draw the attention of the people on the boulevard and tempt them to take a look. When they arrive on the square the entrance to the Art Podium itself is marked by an overhang and an elevated footbridge to bring the visitor to the height of the entrance doors.
The current U shape does a good job at creating this buffer space facing the boulevard side where most people walk, but at the same time creates a back side towards the summer boulevard at the sea side. To connect these two places the route which initially passed under the exhibition spaces now lays on top of the exhibition halls and in this way creating a passage under the building connecting the squire to the summer boulevard.

The last main design idea is the creation of a tower which will draw the attention of the visitors along the boulevard and act as a landmark above the other buildings connected to the boulevard.
image 46.07  
bird's eye view on the south side of the art podium

image 46.08  
street level view from the north side

image 46.09  
street level view from the south side

image 46.10  
street level view from the boulevard

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5.0 REFLECTION

The relationship between the project and the wider social context.

In a globalizing world more and more people, materials and events will travel from city to city for a temporal visit. Examples of such events in the past decades are the Olympic Games and the world football championships. These events provide the region with an economical and social boost but also demand a lot of supporting buildings being constructed to make this event possible (in the case of the Olympic games: stadiums, sport facilities, housing, etc). After the event these specialized buildings could become obsolete if not designed for adaptation. This is one approach where buildings could adapt to a new function, another approach could be to design a building which travels with the event to the next location to serve the same propose again and again. In this way the building can totally focus its performance on serving a single function instead of making a lot of concessions to harbor a new (possibly unknown) function in the future.

The relation between the theme of the studio and the subject/ case study chosen by the student within this framework (location/object).

In the Architectural Engineering studio the emphasis lies on the integration of architecture aspects with the field of Building Technology where the goal is to create synergy between them. The architectural questions (the why..?) question the technical questions (the how..?) and vice versa, where the ultimate goal is to find answers which have a positive effect in both fields. This is what makes logical designs in a technical and architectural sense. This approach has many interfaces with my research on repositionable buildings where the architecture depends heavily on the technical possibilities in building technology to prove the building can perform as expected. On the other side, the architecture pushes the engineering to explore new field and find innovative solutions.
The relationship between the methodical line of approach of the studio and the method chosen by the student in this framework.

The methodical approach of the Architectural Engineering studio is a Technical research into a fascination by choice. In this first half year technical tools should be derived thorough study on the topic to be used in the design process later on.

My research focused on several case studies of modular and repositionable buildings. Which gave me a deeper understanding of: what is that makes buildings modular? why they are modular? and how can modularity be used for repositionable buildings? Although this research gave me many insights on how previous repositionable and modular buildings where constructed it lacked the quantification (maybe in a numerical order) on when which method is more efficient in performance in comparison to the other. This made (in my case) the research less useful in the sense of creating useful “tools” from knowledge acquired by study, to be used in the design part of the graduation project. Instead the research generated (only) extensive knowledge on the subject. This does not mean the research is useless but it did not generated a tool I could use in the design part.

The relationship between research and design.

The objective of the project was to design a travelling art podium which could be disassembled into smaller building parts which would be transported and assembled on a new location.

In addition to this goal the disassembled building parts are an opportunity to assemble them in a different way on the new location which is more suited to the change in context (new context in exhibited art and new context of the location).

The research I conducted on modular and repositionable buildings gave me an understanding of how precedents preformed in relocating a building to a new location but (as explained before) did not generate the design tools. Instead my design tools came from analyzing the designed constructions, building details, manufacturing processes, material uses, etc which where separate studies parallel to the design process. This made my design process more integrated with the research instead of first a research and than a design. While designing the repositionable art podium the questions it generated directed the research to produce answers and when no or impractical answers where found this questioned the architecture if this is the way to go.
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