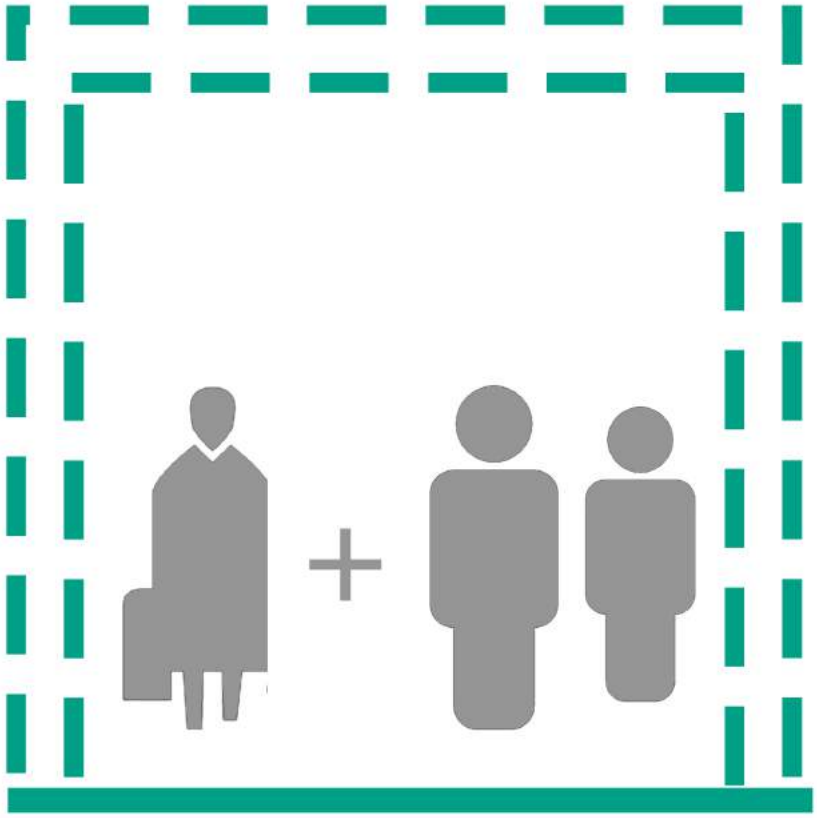
A methodology towards a flexible building system



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Student Ilse Janmaat
4142942
Architecture Job Schroën
Research Pieter Stoutjesdijk

MsC Graduation Studio Architectural Engineering
TU Delft

Abstract

A problem at the moment is the integration of refugees into the community. To make a better connection between the permitted refugees and the residents of the neighborhood a community center will be designed. This community center has to be able to adapt to the changing needs of the users over time. So the building system has to be become flexible in use to be able to meet the requirements of the users.
In this research paper an eight step method is used to design a flexible building system that is adaptable to the changing needs of the users. The existing research product development method, Quality Function Deployment, is the basis of this method as it makes the connection between users and technical requirements. The flexible building system will be used in a community center that will be designed for the residents of the Eastern Islands of Amsterdam and permitted refugees. The needs of the users of the community center will be defined so that the design problems and criteria can be formed. Afterwards the right solutions for several design problems are weighted by user and flexibility criteria resulting in an concept comparison. Every solution will be CNC-fabricated and consist of bio-based materials as those are two requirements to make a future proof building. Out of this concept comparison a concept proposal come up. This concept proposal results to be an system that is adaptable to the needs and houses the equipment storage, fixed functions and temporary walls in one.
The method proves to work for designing an adaptable building system. Still improvements can be made regarding the ambitions and aims of the more softer criteria.

Keywords: *Flexible Building System, Adaptable, Quality Function Deployment method, Permitted refugees, CNC-fabricated, Bio-based materials*

Content

1.Introduction

Right now there are 46.391 refugees in the Asylum seeker centers in the Netherlands(COA, 2016). From 17.000 refugees that entered the Netherlands between January and August 2015 70% of them got a permit(Oving, 2015). All those refugees will eventually be a part of the community. Research (Planbureau, 2011) conducted in 2009 about the refugee groups coming from Afghanistan, Iraq, Iran and Somalia shows the problems we are going to face with the big stream of refugees the coming years. First problem is the civic integration problem, because refugees that follow the integration program feel like the learning of the language mainly happen in their daily life (Planbureau, 2011).The second and biggest problem of integration is the high unemployment rate. In 2009 only around 30% of the Somali refugees found a job, the Iranian refugees have the best result with almost 50%, but that is still low (Planbureau, 2011). The problems of not finding a job relays in four factors; poor health, time spent in the Netherlands, poor command of the Dutch language and foreign qualifications which are not accepted on the market (Planbureau, 2011). The task of 2016 will be the integration of all those permitted refugees, because a fast integration of refugees will prevent unemployment. On the other hand we shouldn't forget about the residents who already live in the neighborhood of Amsterdam for a long period. Often they are scared of a big population of refugees being placed into their community. A lot of progress can be made regarding the interaction between residents and placed refugees (Hollands,2006). To make the integration of the refugees go faster they need the right facilities at the right moment. So we need a flexible living environment that will make the integration go faster and result in a more accepting community. A community center for all the people, where you can follow an integration process but also have other activities as a catalyst for integration with the neighborhood, can make this possible.

Next problem that needs to be improved is the static use of buildings. Most buildings are not able to grow with the changing users need in a relative short time period. If a building is only made for one function, like offices or a public function, that is all that they will be used for until the function becomes unnecessary. At the moment we have seven million m2 of vacant office space in the Netherlands (Gijzel,2016). The problem is that they are not adaptable to the needs of now and the future. As you can see in the table, within 5 years the user will likely change the function of the existing space and within 5-10 years even another user with different function can come into the building. The building should be able to respond to these changes (Gijsbers,2011). A flexible approach to our buildings is necessary for a wide range of reasons: changing family size and groupings, lifestyle issues and remote working. An architecture that is fully adaptable to this fluctuating living and working pattern is needed (Kronenburg,2007). The building system therefore has to be adaptable to the changing needs over time.

Typology of change	Time Span
Trends	daily
Space destination within function	+/-1 year
Spatial layout within function	+/-5 years
Upgrade finishing	+/-5 years
Change user-function	+/-5-10 years
Upgrade comfort	+/-15 years
Functional and spacial change	+/-15 years

Figure1 Typology of change (Own Illus. based on: Gijsbers,2011)

There are two requirements for the building system that are integrate within the research to make a future proof building. First of all the solution should be made of bio-based materials, in order to reduce the harmful effects of materials used nowadays. The building industry accounts for 30% of carbon dioxide emissions, which show an unsustainable industry (Ganotopoulou,2014). It is evident that current building industry plays a big role in the environmental problem. Consequently, building practices should be modified in order to achieve an eco-efficiency of the construction industry. "Architects are the major energy users though the specification of material and components" states Dean Yvonne. They have to make sensible design decisions in terms of limiting the energy demand of the building by its performance and by considering the energy needed in the processing and transportation of materials. Therefore, architects should carefully take into account the desired lifespan of a building's component. A life–cycle of 15-20 years by using materials with less environmental impact, give a sustainable design solution to the changing user's needs for new architectural typologies during time. Bio-based materials are a design answer towards this, since they can allow a short life-cycle without the environmental impact of construction and demolition waste of the non-biodegradable materials. Moreover, they are made from natural renewable resources and the majority needs low amount of energy for their production (Ganotopoulou,2014).

Next to the environmental impact, building construction is a cost intensive process due to the necessary levels of manual labor. Industrial prefabrication has been carried out to build more economically and more efficiently. The next step are the new approaches to industrial construction, based on the application of computer-based production methods, that promise an increase in the amount of creative freedom. The combination of industrial fabrication and manual building techniques result in an interesting aspect for high-quality, economical construction. Therefore a CNC fabrication method will be used to construct the building. The application of CNC production processes means the computer-based control of cutting and milling machines. This system enables variable and differentiated serial manufacturing techniques. Building elements can be easily constructed with CNC milling machines. It will be a new challenge to design and implement constructions with this technology (Dorrhofer,2008).

The research question will integrate the two problems and two requirements to the construction principle :
How to design a building system that can adapt to the changing needs of the permitted refugees and residents in an bio-based and CNC fabricated manner?

A method will be developed to design the required building system. This method needs to make sure the user requirements will be integrated into the technical building system. To come to an answer, an eight step method based on the Quality Function Deployment method will be used to make sure a flexible building system is designed that meet the needs of the users. In this research paper we will take care of the first six steps. First the needs of the different users will be defined. Afterwards the design problems based on the program, climate, construction and architecture will be determined. Next step is to determine the criteria for the building system. If those are created a search to all the different solutions that are bio-based and CNC fabricated will be summed up and a selection of the best alternatives will be made. Finally different concepts will come up out of the evaluation of all the solutions and a concept comparison has to be done to find out what the best concept is for this problem. The conclusion will make clear if this method worked out.

2.Method: Criteria system for adaptable building system

In the industrial production sector methods have been created that aim to develop products that best meet the needs of the user. In case of an adaptable building system the goal is that these needs can be permanently filled, even if the needs of the users are subject to change. It is possible to effectively implement an adaptable building system with the method of Quality Function Deployment(QFD) (Gijsbers,2011). To come to an adaptable building system that can adapt to the needs of the users an eight step method will be used. In this research the first six steps will be handled. The other two will be taken care off during the designing phase.

2.1. Eight step method

Quality Function Deployment is a method to make a connection between the users and the building. It makes it possible to lay a connection between users requirements, product specifications and building specifications. QFD is designed as an product development method. But it is proven that QFD is a suitable method for use in the design of a building. QFD is divided in four houses, in this case only the first one is relevant, known as the House of Quality. This one makes it possible to link the users needs and perceptions to the technical requirements (Gijsbers,2011;Segrera,2009). By using analytical and systematic methods it is possible to step by step realize a building system that meets the specific goals. In this research the method will be used within the architectural field. The problem that comes with this is that sometimes less measurable and more soft factors will be used as criteria and design problems for the building system.
The analytical methodology is divides in the following eight different stages: 1. Needs of the users, 2.Design Problems, 3. Criteria, 4. Alternatives, 5. Concept comparison, 6. Concept proposal, 7. Testing and 8. Final design. The different phases will be explained and elaborated in the following paragraphs.

1. The needs of the users

To figure out what the needs of the users are “The voice of the customer “ has to be determined. There are two steps to fulfill this task. First you identify the needs of the users in terms of Must-be requirements, One dimensional requirements and Attractive requirements. These categories are derived from the “Kano Model, a theory from the product that was developed in 1984 by Professor Kano to characterize the consumer satisfaction. The must-be requirements are the needs that are taken for granted by the user. The presence of such a function will not lead to satisfactory, the absence will be noted and lead to dissatisfaction. In this specific research the Must- be requirements are needs that will lead to the program design problems. Secondly the one dimensional requirements are the real reason why a user will use the building services. The user specifically asks for one or more of these features. The one dimensional requirements will result in the criteria for the building system. At last the attractive requirements are functions that are not expected, but which have a great impact on satisfaction with the building when the function is fulfilled. In this case the attractive requirements are the flexibility criteria. In the scheme on the other page you can see how the needs will contribute to the different steps of this method.(Gijsbers,2011)

2. Design problems

The methodology starts with a specific design task for a certain project. In this case the project consist of an adaptable building system that meets the needs of the users. From this project several design tasks can be derived. The design tasks are divided in four categories, 1. Programmatic, 2. Climatic, 3. Construction and 4. Architectural. Due to the complexity of the design task they should be elaborated in multiple sub-aspects. It is possible to analyze these aspects independent of each other, however, it is not possible to neglect the other layers of the building

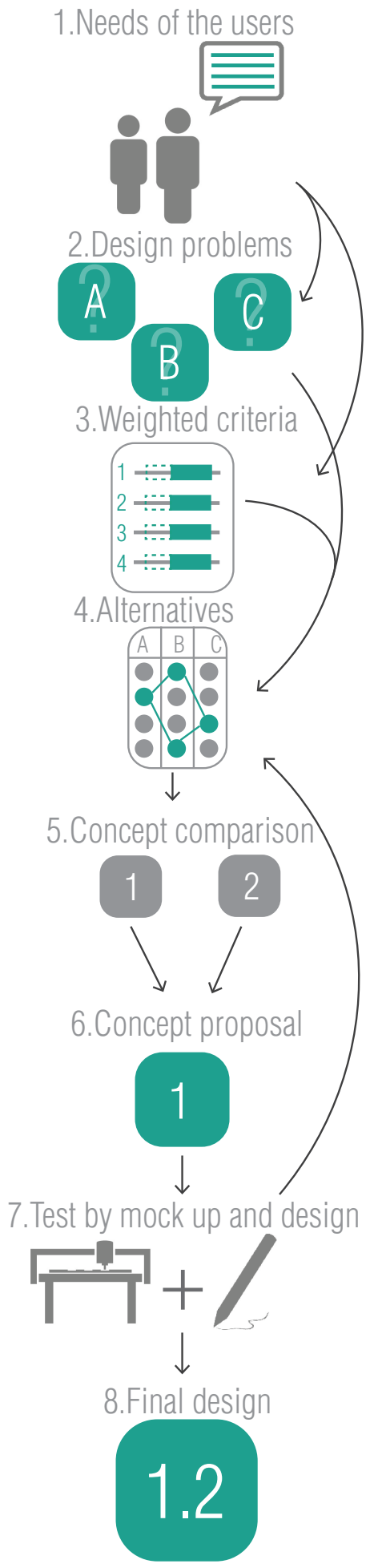


Figure2.1 Eight step method (Own Illus.)

structure.
To solve this problem all the design problems are divided in three categories: Step 1: The construction principle , Step 2: The Flexible building system and Step 3: The relevant requirements for the whole building and building system
To be able to analyze the different design problems and their alternatives, criteria need to be generated in order to make an equal comparison between all the alternatives.

3. Criteria

Depending on the project, criteria should be specified. The criteria are subdivided in requirements and ambitions. The design must meet the specific requirements, in this case to become an adaptable building system. The ambitions can be deduced from users, manufactures and environmental goals. In this case the users will be the driving force regarding the criteria. In the first step the needs of the users are determined regarding the program and social needs. Out of this needs the user and flexible criteria will come up. Every criteria has an ambition to fulfill. The ambition explains how the building system should perform in order to meet the criteria. The ambitions can be derived by specifying the strategies, for a particular project, to form a goal.

Aims

For each specific criteria, aims to fulfill the ambitions need to be determined. The aim specifies in what amount a design solution is convenient to a criteria. The higher the solution scores for an aim, the more suitable the solution is. To specify the aim, first the criteria gets a description. Next step is to specify in what amount the criteria need to be fulfilled and this can be linked to a certain score. The higher the score the more suitable for the design. For the more softer criteria derived form the users it will be more difficult to determine at what stage the ambition is fulfilled. For example when you talk about sound insulation there is a certain number of dB that the wall should be able to reject. But when you talk about grow with the users it is way harder to define at which point the system is growing fast enough with the users needs. In this case you have to make your criteria as concrete as possible and make a very clear description, so you can make a good specification of the aim of the criteria.

Weight

To specify the criteria for every problem, it can be ranked by priority. All the criteria can be compared to each other to make a decision on which is the most important one. With the help of a decision method as compared pair-wise, it is possible to make an order of priority in the relevant functional requirements. This method, which determines in a matrix which is the most important for two different criteria, is suitable to achieve a consistent ranking that determines which individual criteria is the most important. A score of 1 means that more value is given to the criteria in the column in comparison to the criteria in the row. A hierarchy will be created by adding the scores. In this way you can always make a consistent order of priority in the set of criteria. The advantage of this method is the simplicity. A drawback is that this method gives an ordinal result and therefore no value should be given to the distance between the different criteria. It is possible to provide the relationship between the two requirements of a score on the basis of a predetermined qualification. This gives the result more nuance, there is not only determined that one requirement is more important than the other, but also to what extent. Such an approach has the result that the total scores are in proportion to each other, and result in a weighting. By doing this for all the criteria a division can be made between very important, important and less important criteria (Gijsbers,2011).

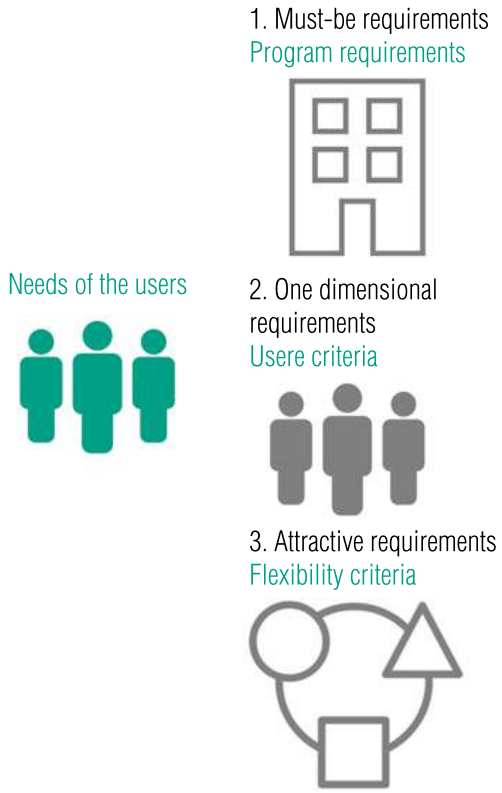


Figure2.2 User needs translation into criteria (Own Illus.)

Criteria 1
Ambition description
Sufficient (minimum aim): Description
Desirable aim: Description

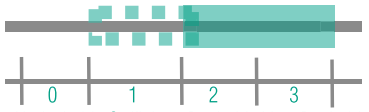


Figure2.3 Setting the aim for a criteria (Own Illus.)

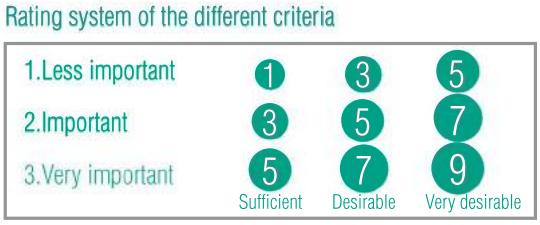


Figure2.4 Rating system (Own Illus.)

Criteria	A	B	C	D	E	Totaalscore	Rangorde
A		1	1	0	1	3	2
B	0		0	0	0	0	1
C	0	1		0	1	2	2
D	1	1	1		1	4	3
E	0	1	0	0		1	1

Figure2.5 Weight system (Own Illus.)

4. Alternatives

The design task is divided in different design problems. For every design problem multiple alternative solutions will be available. In this research every solution has two requirements it has to fulfill. It has to be CNC fabricated and made of bio-based materials, otherwise the possible solution doesn't get on the list of alternatives. The different alternatives for all the problems will be evaluated using the set up criteria and its weight. For each problem the right criteria can be selected so that the design problems only will be evaluated to relevant criteria. Out of this evaluation all the different solutions for each design problem will get a score on each criteria. This score determines which solutions will have the highest end score and present the best choice.

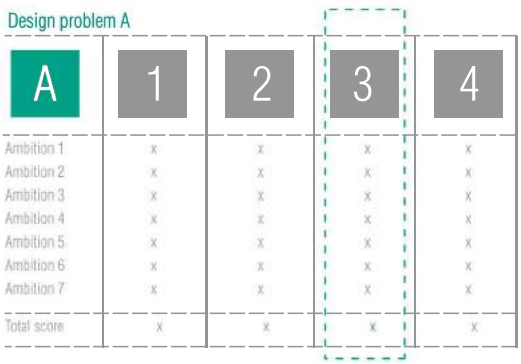


Figure2.6 Alternative selection system (Own Illus.)

If this is done for every design problem you will get a combination of the most promising alternatives. There are three different problems coming with such a combinatorial method. You have to make sure that all the different solutions of each problem are independently chosen and therefore not restrict to each other. Next to this it is hard to find 'all' the right solutions for one problem, therefore subject specific knowledge has to be obtained first and last problem is the amount of alternative solutions that can come up (Roozenburg, 2003). This problem is downsized as the two requirements, biobased and CNC fabrication, result in less possible solutions to consider.

5.Concept Comparison

Selecting all the promising alternatives will probably not give one clear solution for a concept. Some options can result in nearly identical scores. Due to the subjective aspect of decision making the process could contain inaccuracies. Therefore you shouldn't neglect solutions for design problems that show convenient options. This eventually will result in different concept.
Next task is to look to the concepts more in detail and make a comparison between the different concepts. This can be done by the use of analyses. Finally a good estimation can be made to choose the final result.

To make sure the right combination of solutions will be made, while defining the concepts, the concepts are divided in different sub-categories. Especially when the building system has too many design problems to make one concept with all the possible solutions this should be considered. Otherwise too many concepts will become possible. In this research a start will be made for a concept of a flexible building system, later on extra requirements can be added to evolve the concept even more. By fragmentation of the problems in sub-categories the end result will be less subjective and lead to a better concept proposal.

6.Concept Proposal

The comparison will lead to one concept proposal which seems to be the most convenient for the design task.

7. Testing by mock up and design

To analyze the proposed concept tests need to be done. While testing the concept problems will come up. Then the process can become a cyclic process. If a problem is noticed, you can go back to the concept and see how to solve this problem. The test will be evaluated to the specific criteria and this process will go on until all the problems are solved. This step will be done after the research paper is made. The research paper can be used to use other concepts if after testing the concept proposal doesn't turn out to be the best one.

8.Final Design

After testing the concept and making sure there are no problems, a final design can be made. This step is part of the design process and doesn't comes across in this research paper.

2.2 Implementation of the method

In this research paper the first six steps of the method will be shown, each step has its own chapter. Chapter one shows the needs of the permitted refugees and residents of Amsterdam Eastern Islands, who are the users of my building system. In the seconds chapter the criteria based on the users needs and the flexibility of the system will be discussed. In the following chapter the design problems will come up. Only the design problems that will be evaluated in this research paper are discussed in this chapter. Next step is to find all possible solutions for the different design problems that can be CNC fabricated and made of bio-based materials. If all the alternatives are found an alternative selection will be made. In the last chapter the concept comparison takes place. This will lead to one concept proposal. In the conclusion the concept proposal will be discussed and recommendations regarding the used method are given.

3.1.Needs of the different users regarding the community center

3.1.1 Needs for refugees to fasten the integration process

A problem that exists for a very long time is the integration of refugees into the community. Research conducted in 2009 (Planbureau, 2011) about the refugee groups coming from Afghanistan, Iraq, Iran and Somalia are a good basis to see what the problems are we are going to face with the big stream of refugees coming years.

Civic integration program

Since 1988 the civic integration is permitted and this is seen as the start of your integration into the Dutch community. For the broad middle group of refugees, that complete the integration program successfully, this works out very well. Despite most people that follow the integration program feel like the learning of the language mainly happen in their daily life (Planbureau, 2011).

High unemployment rate

The central problem in the integration of refugees is the high unemployment rate. Between 2003 and 2009 the unemployment has already improved a lot, but is still very low. Only around 30% of the Somali refugees have found a job and the Iranian refugees have the best result with almost 50%, but that is still low (Planbureau, 2011).

The problems of not finding a job relays in four factors. The first problem is that refugees camping with health issues, stress and traumatic experiences are less likely to get a job and most of the times it´s a job beneath their potentials. Another problem is that refugee groups that only spent a short time in the Netherlands often can't get a job. In comparison with the established population, immigrants have less work experience in the country of destination and less knowledge about the labor market. Also when there is a greater supply of labor there is a greater possibility on discrimination of refugees. And if there is a scarcity for jobs there is a reason for social exclusion of this group (Guiaux,2008). Also a poor command of the Dutch language reduces their changes on the market. The last reason are the problems with foreign qualifications which are not widely accepted on the market. So the refugees often have to take a job that is low-paid and below their capacities. This results in less perspective on improvement of their potentials (Planbureau, 2011).

Social network and support

The support of a social network will help immigrants to get motivated to participate into the new society. And it will foster the immigrants to get used to the norms and values of the country. Relationships with the established population will help to get a good position on the labor market because they can help you out to find a job.

The Dutch are not very tolerant when it comes to asylum policy and to the attitude of citizens. To improve this tolerance calls for general investment in the neighborhoods and communities where refugees end up is needed. Good information should be given on refugees and must contain meetings and communication between refugees and the host population in order to combat prejudice and promote greater identification with each other (Hollands,2006). Sport can be an outcome as it is a universal language. Sport will encourage people to lay new contacts, learn the language faster, make new friends and feel home quicker. Next to this many refugees suffer from stress, tension, anxiety and uncertainty. Sport gives distraction, if only because you just have nowhere else to think (NOCNSF,2016a)(NOCNSF,2016b).

In the scheme below you can see the actors of the problems and the needs to solve these problems. This needs will be incorporated into the program of the building and also result in criteria for the building system.

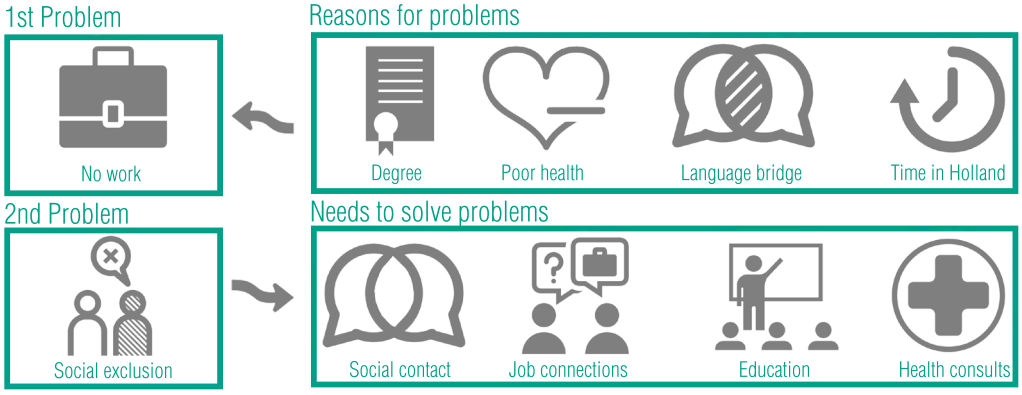


Figure 3.1.1 Needs to solve permitted refugee problems (Own Illus.)

3.1.2 Needs of the residents at Amsterdam Eastern Islands

The Ministry of Defence is downsizing and therefore look with a critical eye to its property (Gemeente Amsterdam,2013). In 2018, the Navy will leave the site and is thus free in its entirety. The release of the Marine Land is a unique opportunity. Development of the land is inextricably linked to the development of Kattenburg. Choices for the layout of the site have direct consequences for the residents of Kattenburg (Buurtorganisatie,2016). The community center with the flexible building system will be build on the Marine Terrein and therefore the needs of the residents of the neighborhood should be taken into account. Defining the needs of the residents at the Eastern Islands will be done in two ways. First the bigger scale looked into discover which needs are lacking compared to the rest of Amsterdam. This is done by a context analysis. After this we will zoom in at the scale of Amsterdam East and find out what the residents envision for the neighborhood.

Figure 3.1.2 Eastern Islands(Buurtorganisatie,2016)

Zoom out: The Eastern Islands compared to the rest of Amsterdam

Maps in the appendix shows the facilities right now and therefore three problems came up.

Sports facilities are leaking

In the close neighborhood there are two football fields, two basketball fields, one jeu de boulle course and a swimming pool. These are all fields that you can use during your own time. There is no basketball or soccer team that you can join in the neighborhood. Facilitating sport courses would be a good improvement for the whole neighborhood. .

Markets

Almost all markets are in the South and West of the city center. The community center would be the perfect facilitator for markets, organized by the neighborhood itself, on a smaller scale.

Open public building

Right now there are several public functions in the neighborhood like a theatre and daycare center, but non of them have an open expression to the neighborhood. The building system would upgrade if this reacts as an open and welcoming building towards the residents.

Zoom in: The residents vision on the Eastern Islands

The Marineterrein is part of the neighborhood Kattenburg and therefore the community center will be developed in conjunction with this area and its inhabitants. The resident platform investigated what the residents wanted with the opening Marine Terrein and its neighborhood. Several interesting ideas came up for the community center. The program of the site should contain public facilities for the city, but also for Kattenburg itself. In the neighborhood they would like to see self-management of green and energy. Besides this they would like to see the neighborhood as a life course resisting environment(Platform,2014).

An area plan made for 2016 for Amsterdam East with the input from neighborhood conversations shows two priorities which need to be integrated into the community center.

Priority 1:Let the residents with socio economic disadvantages have benefit from the economic development of the sub-region.

A relatively large group of residents from the Eastern Islands have an socio economic disadvantage. There are several problem solving measures that could be housed in the community center. First off all the district receive signals that there is a growing hidden poverty. Consultations were residents can go for advice would help. Besides this there are residents who have a big gab with the labor market. The community center will facilitate volunteer work and organize network events and preparation towards your application(Beveren,2016).

Priority 2:Strengthen social cohesion Eastern Islands

The Eastern Islands are becoming more mixed, new residents and former islanders, young and old, vulnerable and strong. The district like to see that these different people connect with each other. Sport activities will be used to bring people in contact with each other in the community center. (Beveren,2016)

In the scheme below you see what the other program function within the community center will be regarding the needs of the residents. Next to this criteria will be taken into account regarding the needs of the residents and the refugees.

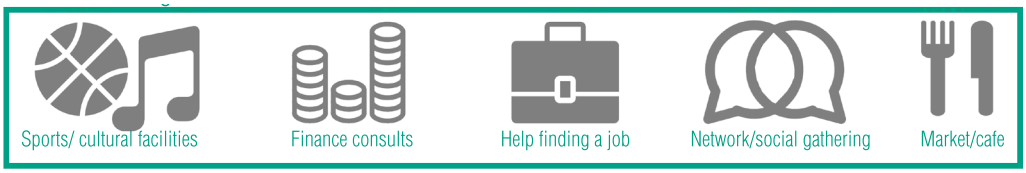


Figure 3.1.3 Needs of the residents of the Eastern Islands (Own Illus.)

3.1.3 Final program of the Community Centre based on different needs over time

Based on the needs of both refugees and residents the scheme below represents all needs regarding the program of the building. This will result in design problems discussed in the next chapter. In the time-line below the scheme you can see when refugees and residents will get in contact with each other. Based on this possible time-line other programmatic design problems can come up.

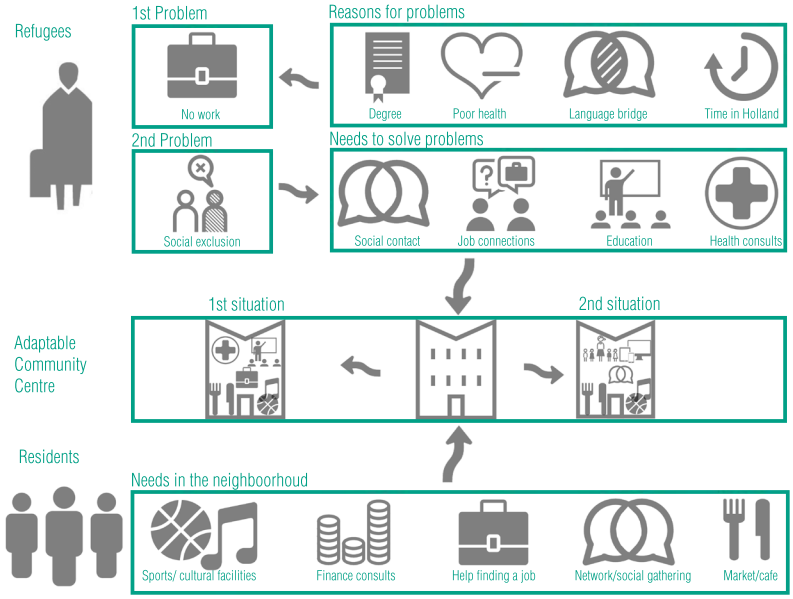


Figure 3.1.4 Needs of the users for the program of the Community Center (Own Illus.)

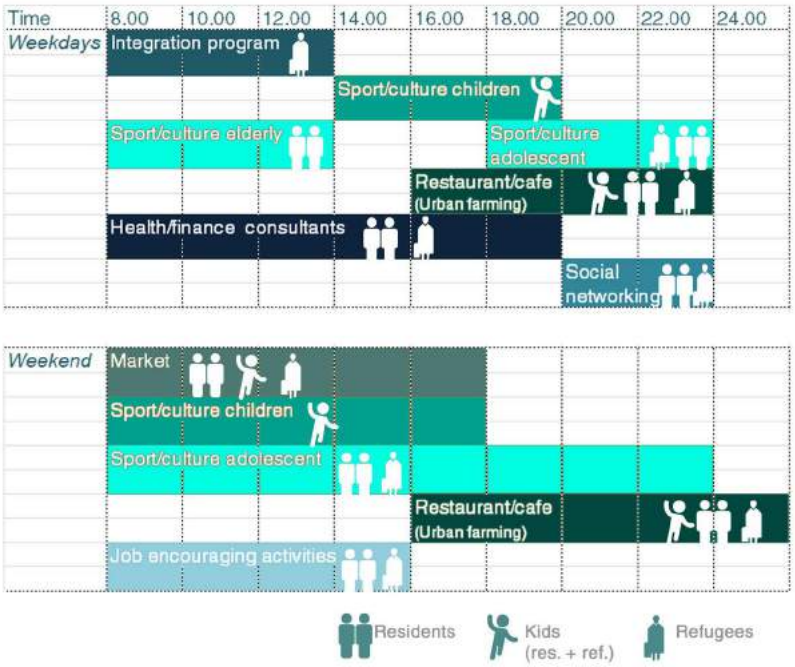


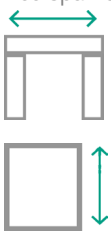
Figure 3.1.5 Possible timeline for the Community Center(Own Illus.)

3.2 Design problems for the building system

Now the needs of the users are described we can define the design problems, step one of the analytic method. The problems are coming from four directions; the program, climate design, construction design and architectural design. A subdivision of three steps is made, because not all the problems can be solved in this research paper. This paper will highlight the first two steps; the construction principle and the most important problems to define the flexible building system. Therefore only the problems that will be solved will be explained, design problems of the rest of the second step and third step will be explained in the appendix.

3.2.1 Program of the design

Free span of 18 meters and height of 7,6 meters.



In the community center sport activities will take place. This requires certain dimensions who will form criteria for the building. The minimum dimensions that will form for the most popular size of a sport hall is 33 x 18 x 7,6 m., these measurements are used as a standard for the design. Therefore the first criteria is a free span of 18 meters, because then it is possible to use the hall for four badminton and tennis fields, one basketball, one volleyball, one football and one hockey playground. A minimum height of 7,6 m. is the next criteria as this will be needed for sports like badminton, basketball and volleyball (Culley,1946).

Placement equipment

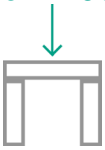
For the use of sport functions a minimum of 12,5 % of the floor area should be available for sports equipment storage. In this building the hall will also be used for other functions, so additional space is needed to store everything. For the dance classes you need mirrors and a good sound system to practice. The mirrors must be at least 2 meter high and as wide as possible (Culley,1946). For the fine arts classes various special equipment is needed, like drawing cabinets and tables. The meeting rooms and restaurant need storage for equipment like tables and chairs. All these different kind of equipment need to be stored in a smart way.

Placement fixed functions

First of all there are the standard fixed functions like toilets, changing rooms and showers who will be used during different activities. Next to this there is the restaurant with some other fixed elements. This restaurant will be small with a limited menu, therefore the space you need per person is 0,83m2. The fixed equipment needed for a restaurant will be a kitchen, storage space and a bar for the drinks. The ratio of service area to total area varies from 25-50%. The net kitchen area will be 15-25% (Neufert,1980).

3.2.2 Construction design

Load bearing



As mentioned before the CNC milled construction elements will have to be load bearing. The most likely material to use for CNC milling is wood. There are various ways to make a wood construction that is also load bearing, as wood is a strong material. In combination with the height of 7,5 meters and 18 meters span this will result in different CNC milled solution.

3.2.3 Architectural requirements

Replacement components

First of all it is important to make sure that the components are movable to make sure all functions can be practiced. The open space needs to be easily transformed into different configurations. To be able to do so replaceable elements need to be designed.

3.2.4 Final set of requirements for the building system

To conclude a final set of all the requirements for the building system is shown. In this research we are not able to focus on all the requirements. In the scheme below you can see how all the different requirements are divided between the three different steps.

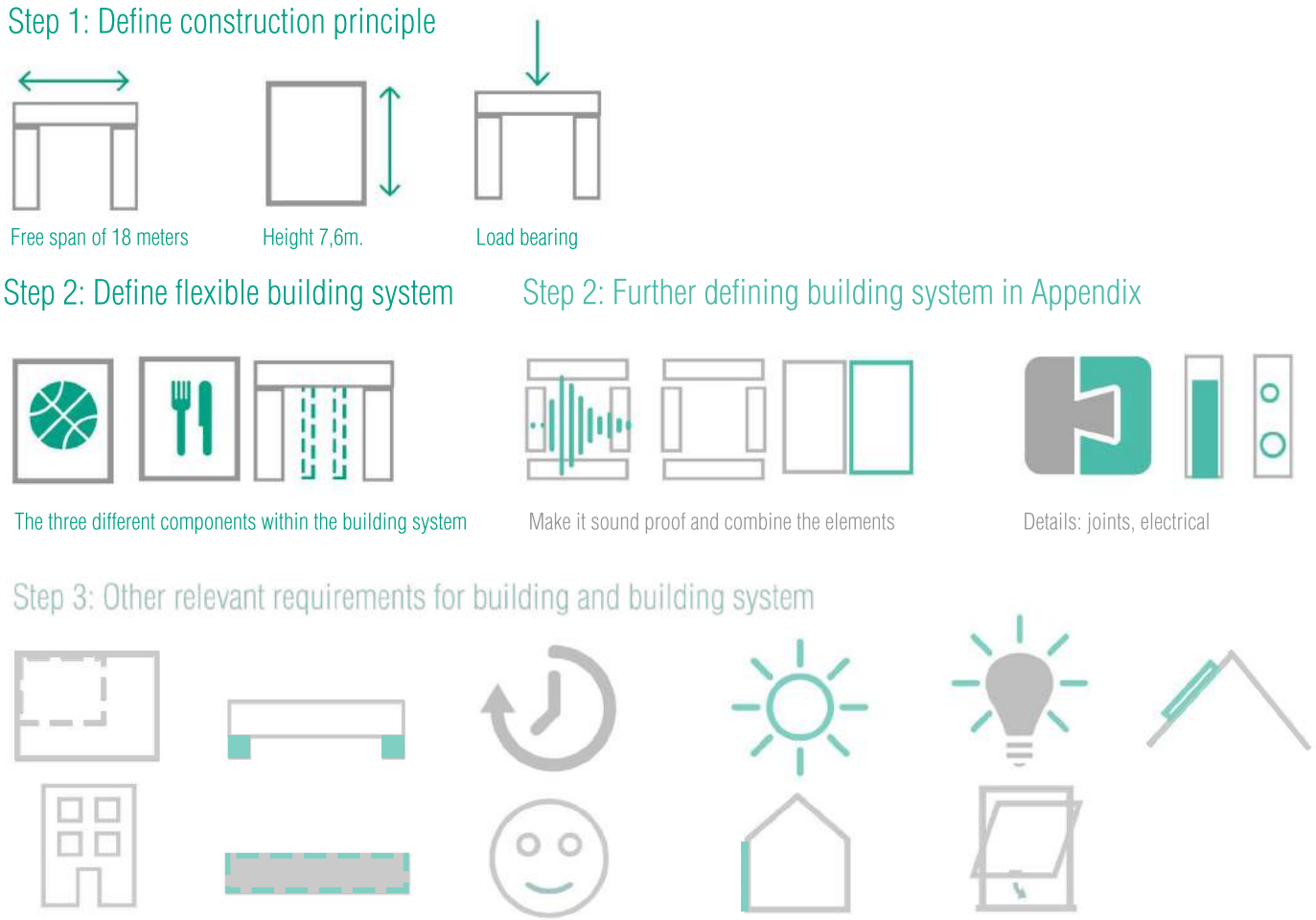


Figure 3.2.1 Design problems(Own Illus.)

3.3 Criteria for the building system: multi-functional/multicultural

Next step after defining the design problems is determine the different criteria. These are divided in the attractive criteria, regarding flexibility for the building system, and the one dimensional criteria derived from the needs of the users.

3.3.1 Flexibility criteria

The flexibility criteria are the attractive criteria for this project because “flexibility is the ability of a building or building product that allows adaptation to the demands and wishes of the users”(Gijsbers,2011). The goal is to be adaptable to the changing needs over time of the permitted refugees and residents. If an easy transformable and adaptable construction is created they have the freedom to change configurations of spaces themselves. This would be the perfect solution for an optimal used community center and in the end this would result in reducing costs because less space is needed for all the different functions.
To make sure enough flexibility is maintained in the building system four criteria are defined based on the thesis of Gijsbers. First of all it is prior to provide easy handling methods. The easy ergonomics of the building system is the first criteria. The system should be easy to construct so in the end it is simple for the neighborhood to transform this during the day. Next to this the elements have to be easy to demount. Therefore the next criteria will be to use as less different components as possible. If there are too many different pieces it will be a hard puzzle to solve. And at last the adaptation to change over time will play a key factor. This results in the two criteria for the building system. Our criteria on the short time span will be the adaptation of the space during the day. Finally the long time span is also important, as some functions will become unnecessary, and will result in the criteria of easy disassembly over the coming year/years.

3.3.2 User criteria

It is important to connect the social criteria to the building system. Therefore several criteria will be lined up to be sure the users needs will be reflected in the building itself. First of all it is important to bring everyone in contact with each other during the different activities in the community center. Contact is an important factor but some activities need more privacy then others. Therefore the contact has to be flexible, so you can choose whether you have a closed, open or transparant space. The first criteria will be the flexible contact. Not only the contact between several activities is important, also this building should be open to the public space. Therefore the next criteria is to be open up to the community, so that everyone will be feeling welcomed by the building itself. Next important goal for the residents is that they can manage the building themselves. It is a collective building, the community can and will decide which functions will take place at a certain moment. An important criteria of the building is the self management and control of the functions. To make this possible the building also has to be able to grow together with the development of the users, which is the fourth criteria. If the integration of the permitted refugees has ended the building has to be able to adapt to this big change. That means that it can handle different functions over time. The last criteria is to create a mixed architectural expression for the building system. Different countries have different ways of designing public spaces. To give you an idea this two projects reflect the personalizing of a project;

For the construction of the Luchtsingel 17000 wooden boards are required. Everyone can participate by buying a plank, element or part of the bridge. The board bears your name, wish or message to the city. In this way the bridge turns into an object of the whole community. It personalizes the architectural object. (Stichting Luchtsingel, 2016)


Figure 3.3.1 Luchtsingel(Stichting Luchtsingel,2016)

For the design of the Kolenkithuis at Amsterdam-West they used the conclusions of the study “Nestelen in de stad” The building is a block of one family residences, where the different wishes of families with four children or more has been taken into account. The facade is built in yellow stone bricks whereby every house can be read separately due to a varied decorative brick pattern. (Architectenweb,2016)

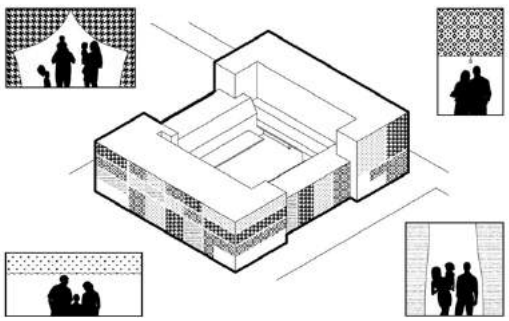


Figure 3.3.2 Kolenkithuis(Architectenweb,2016)

3.3.3 List of criteria and its ambitions

The criteria are defined so now the ambitions for every criteria will be specified and an aim will be derived from the ambition to fulfill. The scheme below contains the ambition and aim of every criteria and an explanation of how the aim can be fulfilled in a sufficient and desirable way. A clear ambition is set so it is easier to set a harder aim for the soft criteria. The drawback of setting hard aims to a softer criteria is that the aim itself could become more subjective as you can't be a 100% sure of the fact that the right aim is set. But the big advantage is that the rating of the different solutions can be done in an objective way and doesn't turn out to be a subjective choice.

User

1. Flexible contact – open/closed & private/public
The building has to be adaptable to private and public functions as the space can become open, semi-open or closed in order to fulfill the needs.

Sufficient: Windows that can be opened/closed
Desirable: Openable/ transparant elements

2. Open to surroundings/ public
To attract the whole community to the building the building should have an open facade to attract the public.

Sufficient: 35% of the facade has to be open
Desirable: Building opens up to 50% or more of the facade(Ministerie van Binnenlandse zaken)

3. Community self-management/control
The building system has to be easy to control during the day to fulfill the different needs.

Sufficient: People can take all the equipment they need
Desirable: People can change configuration of space in +-10 min.

4. Grow with the residents
As the community changes the needs will change and the building should be able to adapt to those changes

Sufficient: Parts that are not needed anymore can be removed
Desirable: Useless parts can change to another function

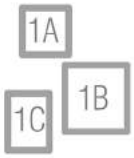
5. Mixed architectural expresion - multicultural
As the building has a multicultural purpose the architectural experience should be mixed as well.

Sufficient: Architectural form recognized by multi cultural users
Desirable: Used architectural principles from several countries

Flexibility

1.Ergonomics – Easy handling methods
The building system should be easy to install on site as volunteers can help to construct the building.

Sufficient: If fast assembled by skilled labor
Desirable: If fast assembled by unskilled labor guided by skilled people



2. Not a lot of different components
There should be a minimum of components otherwise it will be to difficult for the users to get used to the sytem. As too many variety requires more knowledge.

Sufficient: Less then five totally different components
Desirable: One component is made with slight variations to create all the desired forms

3.Adaptability of the different components over day
The building system should have to be very flexible to be adaptable to all the different kind of functions it has to fulfill during the day.

Sufficient: The space can change to one other function
Desirable: The space is multi-functional

4.Disassembly ease – Adaptation to change over time
The end goal is that the building system is easy to remove or transform to a total different configuration when needed.

Sufficient: The building components are reusable
Desirable: The building components can be reused or biodegraded

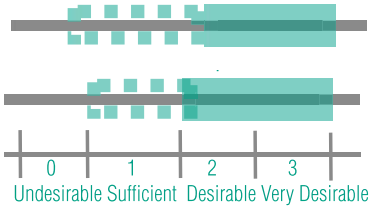


Figure 3.3.3 Ambitions and aims of the different criteria (Own Illus.)

3.3.4 Weight of the criteria

Next step is weight the criteria with each other. If a criteria is more important then the other it gets a score one, if not it gets a score of zero. This results in a total score. The total score is transfered to a rating system of 1. Less important, 2. Important and 3. Very important. As you can see below in the rating system these importances correspond to a certain point system. The more important the more points the solution will get if it scores in a sufficient, desirable or very desirable way to the different criteria.

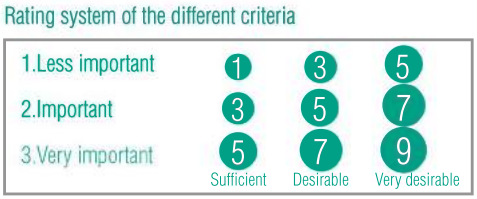
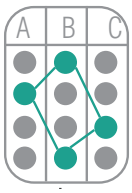


Figure 3.3.4 Rating system(Own Illus.)

Criteria	Flexible contact	Open to surrounding	Community self control	Grow with the residients	Mixed architectural expression	Ergonomics	Minimize different components	Adaptability over day	Disassembly ease	Total score	Rate
Flexible contact		1	0	0	1	0	1	0	1	4	2
Open to surrounding	0		0	0	0	0	0	0	0	0	1
Community self control	1	1		1	1	1	1	0	1	7	3
Grow with the residients	1	1	0		1	1	1	0	1	6	3
Mixed architectural expression	0	1	0	0		0	1	0	0	2	1
Ergonomics	1	1	0	0	1		1	0	1	5	2
Minimize different components	0	1	0	0	0	0		0	0	1	1
Adaptability over day	1	1	1	1	1	1	1		1	8	3
Disassembly ease	0	1	0	0	1	0	1	0		3	2

Figure 3.3.5 Weighted criteria with final rate(Own Illus.)

3.4 Alternatives



Following is to define all the possible solution to the set design problems. In this research there are two extra requirements that the solutions must meet to be taken into account. The solutions have to be CNC fabricated and producable in biobased materials. First is explained why it has to be CNC fabricated and contain biobased materials after this the different solutions are presented and the alternative selection is made.

3.4.1 Why CNC fabrication?

Digital fabrication is an efficient method to make a cost effective building system. Also the labor by men is reduced and not difficult. If the structure is easy to put together and not a lot of extra tools and skilled labors are needed, the possibility of making it an integrated project with the neighborhood is there. The goals is to make a partly/whole DIY-structure where the refugees and residents who don't have a job can come together and build up the construction. Then they know the building like it's their own and know how to handle transformations within the building to adapt to the different needs. A small research in the appendix shows which CNC fabrication method is best to use in this case. After a good comparison, CNC milling is the best solution to make a flexible building system. This technique will be taken into account while finding solutions for the different design problems.

Figure3.4.1 CNC fabrictions reasons (Own Illus.)

3.4.2 Why Bio-based materials?

One of the main reasons to use bio-based materials is the sustainability factor. The biodegradability of a material refers to its potential to naturally decompose when discarded. Organic materials can return to the earth rapidly, while others take a long time. The bio-based materials are good to use for this social problem. After a short term of 5 years most refugees will be fully integrated into the community, therefore the building's function will change over time and has to be able to be either reused or biodegradable when parts of the building are not needed anymore. Most materials have useful years left when the building is decommissioned, and may be easily reinstalled in a new site or new building purpose (Kim,1998).

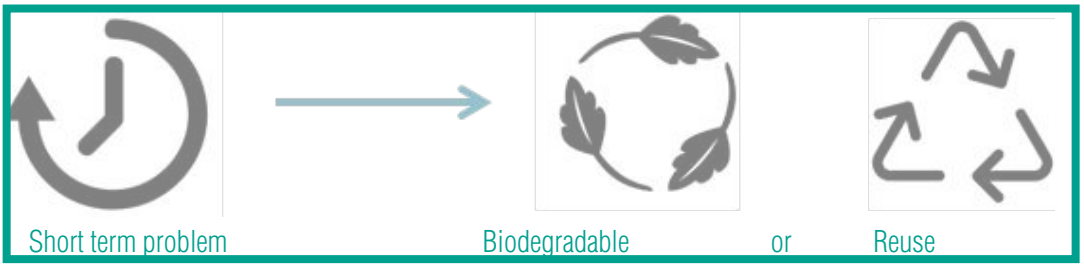
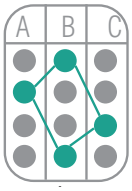


Figure3.4.2 Bio-based material reasons (Own Illus.)

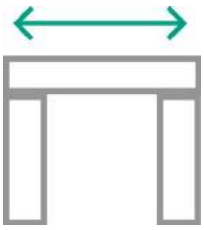
Using bio-based materials means using natural materials. The natural materials are generally lower in embodied energy and toxicity than man-made materials. Also they require less processing and are less damaging to the environment. Many materials, like wood, are theoretically renewable. When natural materials are incorporated into building products, the products become more sustainable (Kim,1998). The goal is to make it out of natural materials totally so it becomes 100% sustainable.
The most effective and commonly used material for a CNC milled building system is wood. Next to wood there will be other materials used for insulations, transparency and other building needs, therefore a small research is done on possible materials to use for the building system and can be found in the appendix.

3.4.3 Selection of Alternatives

Step 1: Define construction principle

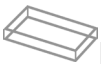


To make sure the building system can be as flexible as possible a separate construction principle will be used that will give the building system the freedom of design. The large span and height are significant problems that will be tackled on it's own. The construction principle also has to be able to be CNC fabricated and made out of bio-based materials. The mayor benefit of the separate construction is that the building system itself doesn't have to be load bearing next to all the other design problems it has to solve as shown in figure 3.2.1.The flexible building system itself still needs to be able to fill the construction reaching the height of 7,5 meters and travel a span of 18 meters. The building system and construction principle are two different steps, but need to be integrated with each other to become a building.



Large span of 18 meters

There are several solutions to make a span of 18 meters in a CNC fabricated and bio-based solution. The material that will be used in all the different options is wood. As it is a bio-based material and good for making large free span constructions.



Hollow slab floor

The Kerto Ripa hollow slab floors are made of laminated Metsa Wood. Because of the prefabrication it has a good dimensional stability. It is relatively light weighted and therefore quite easy to construct. The glue technique makes it possible to get free spans of 20 meters long. The disadvantage is the glue technique, because the disassembly possibilities are lower (Kennisbank).

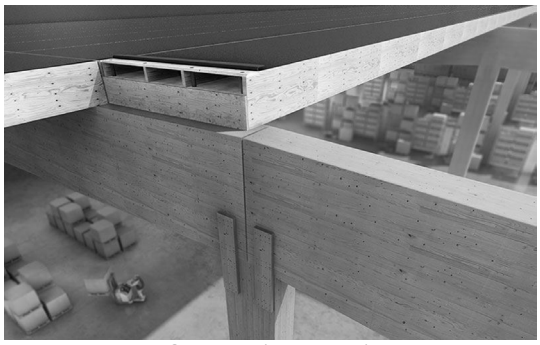


Figure3.4.3 Hollow Slab Floor (Kennisbank)

Beam

Next option is to make a beam to span the 18 meters. The Baubuche beam is made of 40mm thick beech laminations, bonded parallel to its grain. Different from normal beams is the use of hardwood instead of conventional softwood structures. Beech is a hardwood in plentiful supply from sustainable forestry in central Europe. Unlike plywood the Baubuche is designed especially for use in timber constructions. The veneers are therefore predominantly aligned parallel to the grain so as to give a main load-bearing direction. Another difference from plywood is that laminated veneer lumber is supplied in much larger sizes. The advantages of this method is its high strengths that allows the beams to be used in slender structures for heavy loads and large spans. The superiors strength and stiffness of the beam allows smaller cross-sections which in turn means big savings in material. Also it saves on connectors, and thus reduces costs due to its high density and homogeneity. It is an easy construction method, whereby the building system components could fit in perfectly(Pollmeier).

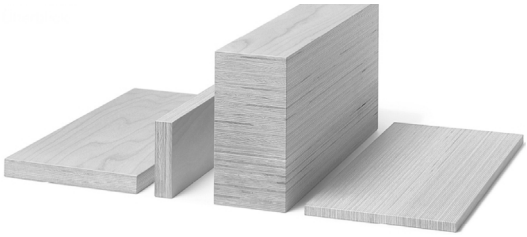
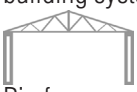


Figure3.4.4 Baubuche Beam (Pollmeier)



Pin frames, Trusses

Pin frames and trusses are the third option to span the 18 meters.
Greather depths enable the use of trusses and frames because the load-carrying mechanism is by way tension and/or compression. An advantage of this method is that the frames create an impression of lightness and spacious interiors. Main disadvantage is the amount of different elements that need to be CNC fabricated that is higher than with a beam or arched structure. The baubuche beam is already been used in frames before as seen on the right and can gaurantee a slender construction (Natterer,2004).

Figure3.4.5 Frames (Pollmeier)

Arches

Another option is to make arches spanning 18 meters. In the sports hall at the right continuous crossed arcs-columns made of laminated timbers are used to make the large span of 22 meters. The open structure makes it possible to use a lot of natural light in the sports hall. Next to this it is easy mountable as only

Figure3.4.6 Gymnasium Régis Racine(Guillame,2011)

one element is needed for the full span instead of beams and columns. The big advantage is the amount of elements and easy to assembly (Guillame,2011).

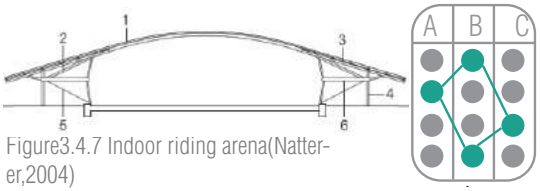


Figure3.4.7 Indoor riding arena(Natterer,2004)

Barrel vaults, domes and hyperbolic vaults

Last option is to make a vault or dome to span the 18 meters. The barrel vault at the right is an indoor riding arena. The roof consists of a glued timber ribbed shell spanning 20 meter and supported every 5 .5 m on trestles. These carry both the vertical and horizontal loads down to the foundations, whereby the horizontal forces from the shell are taken by the steel edge beams spanning between the columns.

Another variation is a lattice dome, the one on the right has an shell-type lattice grid covering an area of 4700 m2. When flat, the 50 x 50 mm battens in two, three or four layers form a regular orthogonal 500 x 500 mm mesh.

Last option in this category is to have an hyperbolic vault. The example has a sequence of 10 hyperbolic paraboloid shells forms the roof over a swimming pool. Each shell segment rests on four reinforced concrete columns placed 21 meters apart. Overall stability is guaranteed by the shell segments acting as plates. Continuity results from the trussing and the fixed-base columns. Main disadvantage is the complexity of the structures, therefore it is less easily to assemble and disassemble(Natterer,2004).

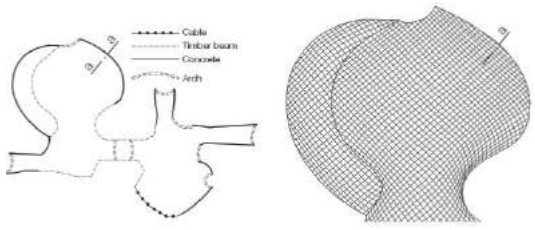


Figure3.4.8 Shell-type latice dome(Natterer,2004)

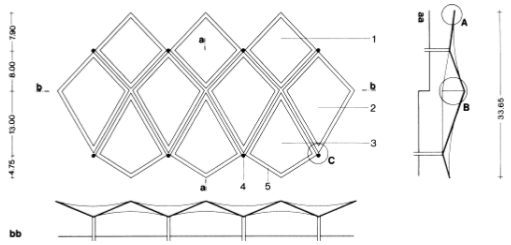


Figure3.4.9 Hyperbolic vault(Natterer,2004)

Alternative selection of the load bearing structure

The two best solutions to construct the span of 18 meters is to make a beam or ached construction. Both methods have the same score and are the best ones because of several reasons:

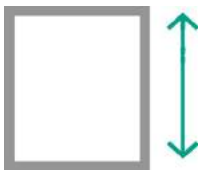
1. The adaptability of the system is high as it gives a lot of freedom to the design of the building system elements.
2. Its simplicity is its strength in this case, because they will be easy to assemble and disassemble.
3. Last but not least they both score best on the amount of elements.

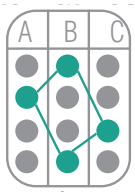
For the arches only one element is needed and for the beam structure only a beam and column will be needed to construct the building.

Large span		Beam	Arches	Trusses/pin frames	Vaults/Domes	Hollow core slab
Different elements	1	5	5	3	1	3
Adaptability	3	9	7	7	5	9
Disassembly ease	2	7	9	7	3	7
Flexible contact	2	5	5	5	3	3
Open surrounding	1	5	5	5	1	3
Arch. mixture	1	5	5	5	3	1
Total score		36	36	32	16	26

Figure3.4.10 Alternative selection large span (Own Illus.)

Height 7,6 meters





Solid timber

The most commonly used column is the solid timber column. This column can be produced in different forms between round, square or rectangular. The permissible loads that can be carried depend essentially on stability elements and can be influenced by many constructional measures. The greatest are those of material conditions and accuracy during the fabrication. This should be taken into account when CNC fabricated.

Figure3.4.11 Solid column (Natterer,2004)

Battened and laced columns

Next option are battened or laced coumns. If you use battened or laced columns you will need less material for the same strength. Columns made up of several embers are divided in two groups, one that is joined continuously and one held apart with transverse members in which buckling must be assessed for the whole system and the flanges individually. To make battened columns you can use a pinned base and intermediate timber spacer blocks or a pinned base in combination with connecting boards. Main disadvantage is the amount of different elements needed (Natterer,2004).

Figure3.4.12 Battened column (Natterer,2004)

Vertical truss

If you decide to make a column only at one side a vertical truss is an option. This makes the column stiffer and able to transfer more loads. Their task is to prevent buckling, overturning or punching problems. It is also designed to withstand horizontal loads such as wind, asymmetric snow loads, imposed loads and impacts which must be transfered into the subsoil. A frame can be fabricated to make it possible to have larger clear openings. Special care should be taken to ensure adequate stiffness, especially with large areas of glazing. If chosen for the trusses the quantity of material required is considerably less, but the connections are more complicated and amount of different elements is higher(Natterer,2004).

Figure3.4.13 Propped column (Natterer,2004)

Propped column

Next to these four options there are the propped compressive members. Propped columns are suitable for reducing the buckling length and hence the moments on compressive members. Unwanted out-of-plumb effect or those that occur in service need to be taken into account in the resultant loads (Natterer,2004). The disadvantage of construction is the lack of freedom in design and openings.

Figure3.4.14 Crossed column (Natterer,2004)

Crossed columns

Last option is to use crossed columns. The restrained members are made from solid cross-sections consisting of squared timber or glued laminated timber. These are subjected to internal and external loads. The elasticity of the connection is taken into account by way of rotational stiffnesses (Natterer,2004).Main disadvantage is the lack to open up the facade to the surrounding.

Alternative selection of the load bearing structure

The solid beam is by far the most promising alternative for this problem. There are two main reasons for this:
1.The disassembly ease is very high as this is the most simple way of constructing columns.
2. Every column can be the same and consist of one element. All the other columns have extra connection and therefore are consisting of different elements. This doesn't make the production process easier.

Height 7,6 m		Solid	Battened/laced	Trusses	Prop/trestle	Crossed
Ergonomics	2	7	7	7	7	5
Different elements	1	5	3	3	3	5
Adaptability	3	9	9	9	7	7
Disassembly ease	2	7	3	3	5	7
Open surrounding	1	5	5	3	1	1
Grow	3	7	7	7	7	5
Total score		40	34	32	30	30

Figure3.4.15 Alternative selection height (Own Illus.)

Load bearing structure

To make a load bearing structure there are three different solutions to the structural principle of connection between the different components.

Hinged connection

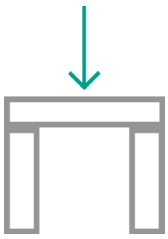
First option is to use a hinged connection. The freedom of design is reduced significantly if you use a hinged connection. You are not able to design a stable building with one open façade. This connection carry shear and axial forces but not moment between different members. Extra secondary structural measures are needed to make sure the building is stable. Hinged connection allow the jointed members to have different rotations but the same displacements. The hinged construction is easier because of the assembly ease of the building. It is convenient to place the modules because only one connection has to be fixed and all the connections are the same.

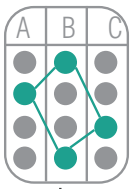
Fixed connection at the bottom

Using fixed bottom connections, means that almost all bending moments resulting from vertical and horizontal loads are taken care off. The main advantage is that no extra secondary stability elements are needed. Also it has more freedom in the design of the rest of the building system, so you are able to design an open head façade. Disadvantage is that you need two different type of connections instead of one.

Fixed connections

The last alternative is using only fixed connections. This connection carry moment, shear and axial forces between different members. All members including in such a connection have one and the same rotation and displacements. The freedom of the design of the building system is also good. Just like the hinged connections the building ease is improved, because all the connections are the same. The downsides of this principle are the more connections that need to be assembled.(UACG)





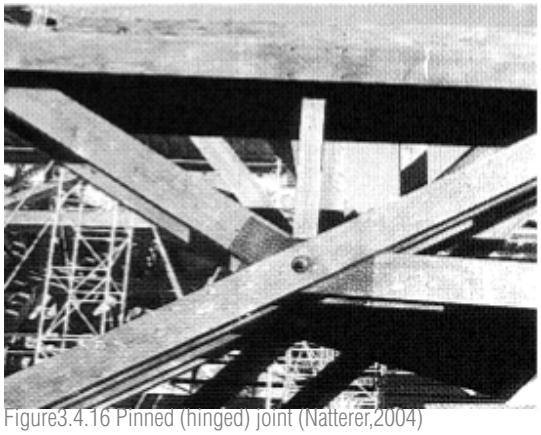


Figure3.4.16 Pinned (hinged) joint (Natterer,2004)

Figure3.4.17 Rigid (fixed) joint (Natterer,2004)

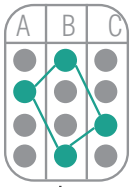
Alternative selection of the load bearing structure

In this case also one alternative is by far the best solution. The fixed connection is the best out of three because of the following reasons:
1. It scores best on adaptability as it gives the building system most freedom for design and possibilities to be open to the surrounding. This results in a construction principle that will be able to open up to the community and adapt to changes of the users.
2. The overall score for the rest is steady and therefore this is the most reliable option to choose for.

Load bearing		Hinged	Fixed bottom	Fixed
Ergonomics	2	5	3	5
Adaptability	3	7	7	9
Disassembly ease	2	7	5	7
Open surrounding	1	1	5	5
Grow	3	5	5	5
Arch. mixture	1	1	3	3
Total score		26	28	34

Figure3.4.18 Alternative selection load bearing (Own Illus.)

Step 2: Define flexible building system



To define the flexible building system the terms of flexibility, adaptability and transformation will be explained first.
In a spatial sense, there are four flexible forms to distinguish: furnish flexibility, layout flexibility, parcel of land flexibility and volume flexibility. In this case the flexibility inside the building is required, therefore the furnishing flexibility and layout flexibility will be discussed. The furnish flexibility only makes it possible to change the configuration of the loss standing facilities. The user wants to change the arrangement of the space.In layout flexibility, the floor plan remains flexible so the walls are free to place and optimum use of space is possible.
Next to this there are three types of functional flexibility distinguished: the Versatile flexibility of space, upgrade flexibility, function neutrality. There is no need for upgrade flexibility as the space is a new designed space. But the versatile flexibility of space and function neutrality are important actors of flexibility for this design. The versatile space can change over time in a short time span without doing any structural adjustments. However, the function neutrality has the capacity to house different functions without or with limited structural changes.
The four ways of flexibility are shown in the figure on the right to make clear what the differences are between them.

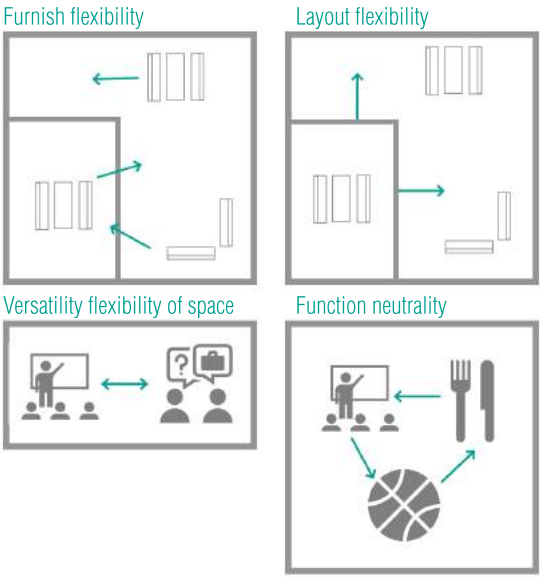


Figure3.4.19 Four flexibility options (Own Illus.)

Most important for the flexible building system is to be adaptable to the needs of the users over time. Adaptability is a technical quality at the service of the flexible use of the building. The definition of adaptability, which is used in the present study is:
The ability of a building component to be able to undergo permanent physical changes in the service of the flexibility of users, without or with only small impact on the other building components (Gijsbers,2011).

The different forms of flexibility are processes of transformation. A transforming object has certain unique characteristics. These qualities relate to its behavior, a process that is: complete three-dimensional, smooth and continuous and reversible and repeatable.
It is quite hard to find designed object of this complete, smooth and continuous transformation (Klassen,2006). Therefore a list of all possible kinds of transformations in buildings are shown at the right. Six categories are divided: rotate, up & down, shiftable, foldable, multi-function and movable. For every design problem the possible solutions will be evaluated, summing up the pro's and con's for each solution, so in the end the best solution(s) will come up.

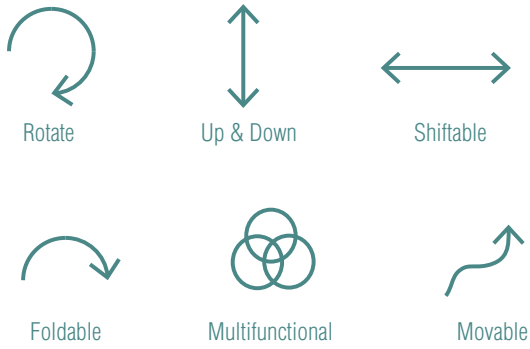


Figure3.4.20 Adaption options (Own Illus.)

Placement of storage

Multi-functional

The first way of stacking all the different equipment for all different functions is making multi-functional walls. If your walls are not only space dividers but also storage closets you have an optimal use of space. The advantages of this solution is the freedom of design you create and it is very easy to handle. Disadvantages are the thickness of the walls because you need to be able to store everything. Next to this it could result in less freedom in designing the façade, because of the many closed walls for storage.

Foldable

The second option is to use folding walls and unwrapping several equipment. In the example you can see a childcare where the wall is becoming a fold-out slide for the children. The big advantage of this method is the easy handling method and the flexibility of the space that stays intact. The downside of this solutions is the fact that you need a lot of walls to stack everything and will lose freedom in designing an open building.

Movable

The most common way of storage equipment is to reserve space or make closets to store everything and when needed move it to the right place. This could be a good solution when the equipment you have to storage is too big to store it in a wall. Despite this there are a lot of disadvantages; you will need an extra component like curtains or a movable wall to hide all the storage components. Therefore, the integration of the building system and the problem solving solution is minimal.

Up & down

Last option to solve the problem is store the equipment in the ceiling instead of the walls. As this building has a lot of free space left when no sports games are played there lies an opportunity in this solution. The advantage is the space that is coming free in your floor plan because there is a lot of extra freedom compared to all solutions above. But the mayor disadvantage will be the ease of this solutions, it is hard to install all the equipment into the ceiling and it will require technical installations to operate the system. The main function for this solution is to store big things, like furniture and big sport equipment (for example goals).

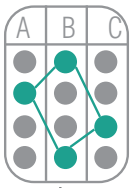


Figure3.4.21 New Kindergarten (Hurnaus,2011)

Figure3.4.22 New Kindergarten (Hurnaus,2011)

Figure3.4.23 Gonzalez estuido Urgari (Egion,2013)

Figure3.4.24 Appartment Madrid (Dezeen,2014)

Alternative selection of the equipment storage

The scheme shows in this case there are two best alternatives. The difference between the scores is so minimal that both scores should be taken into account as an option for the concept proposal. The multi-functional and foldable elements are both an option because:

1. The ergonomics of the elements are better because it is the easiest way of changing without heavy duties or extra tools.
2. They both have a good overall score on all the criteria, especially the self control and adaptability which are two of the most important factors. Both methods are very simple to understand for the users.

		Multifunctional	Foldable	Moveable	Up & Down
Ergonomics	2	7	7	3	5
Different elements	1	5	5	1	5
Adaptability	3	7	9	5	9
Disassembly ease	2	7	7	5	3
Open surrounding	1	3	3	3	5
Self control	3	9	9	9	5
Grow	3	7	7	9	7
Total score		45	47	35	39

Figure3.4.25 Alternative selection storage equipment (Own Illus.)

Placement of fixed functions

The placement of the fixed functions are more difficult, because the size of the object is way bigger and the connection to the grid and drains need to be taken into account.

Foldable

First of all the function could be foldable. Especially when a restaurant needs to be created. A small space is needed to store the restaurant and only when opened the restaurant can fold out and be used. You can immediately store all you furniture and storage of food and drinks in there. Next to a foldable solution it is also a multi-functional solution. The disadvantages of this solution is that you have to be careful designing private functions because you don't want to make it open up to the public.

Movable

The second solution to give the floor plan enough freedom is by making the fixed functions movable. For seating space this is an ideal option. As discussed before the disadvantage is the fact that you have to be able to plug in your movable restaurant, toilet and showers on the drains and electricity grid to be able to function. So this is a big task for the plumbing and electricity grid to fulfill.

Up & Down

This solution is almost the same as the foldable one, but instead of folding out you move the elements up or down. The advantage compared to the folding method is the fact that you don't need any floor space to upon up the function. The disadvantage is that will not save any space for the function as you can see in the Steirereck restaurant or make the space more flexible.

Fixed

Last option is the most commonly used in the architectural field, making the fixed functions literally fixed in the space. If you choose for this options the ingenuity lays in the component itself. You could make a standard toilet room with the same fixed dimensions as before, but you could also choose to do it in a different way as shown at the right. The toilets are turned into pods, so the space around it can be freely used for other functions. In this case as minimal space as needed will be used and the space around it can be used freely for other functions, making it possible to still be creative with the floor plan.

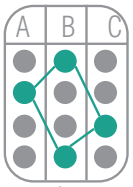


Figure3.4.26 Container Restaurant(Minhacasa,2013)

Figure3.4.27 Treehouse(Brouns,2014)

Figure 3.4.28 Steirereck Restaurant (Pierer)
Figure 3.4.29 Sketch Restaurant (Akhavein)

Alternative selection of the placement of fixed functions

In the scheme you can see that in this case there are two best alternatives: foldable or movable. They are most suitable because of three main reasons:

1. High adaptability to the users can be guaranteed.
2. It is easy to control by the users because it is a very simple method, no extra tools are needed to change the object.
3. The disassembly process is easier because you can either move out the movable element or remove foldable parts you don't need anymore.

Placement fixed		Foldable	Moveable	Up & down	Fixed
Ergonomics	2	7	3	5	7
Adaptability	3	7	9	7	5
Disassembly ease	2	7	5	5	3
Flexible contact	2	5	5	7	3
Self control	3	7	9	7	5
Grow	3	7	9	5	9
Total score		40	40	36	32

Figure3.4.30 Alternative selection placement fixed functions (Own Illus.)

Replacement of components

To make it possible for the residents to transform the building in different configurations for several functions the walls have to be easy to replace .

Foldable

Making foldable walls results in a lot of different configurations. You can either fold it around in the x-axis or y-axis. The advantage of this method is that you don't need any extra space for creating walls in other directions then the main directions of the fixed walls. The disadvantage of this method is the lack of privacy while folding some of the walls. Another limitation is the length of the foldable elements of the wall.

Moveable

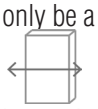
The next solution for making a replacement component is to make it move. The advantage of this solution is the freedom you give the residents to make different configurations during the day. The disadvantage is the time you spent making another configuration and how many people you need to do this fast.

Up & Down

There is a lot of space available at the ceiling to let walls go up & down when needed. The advantage is the freedom in space and the fact that no extra space is needed at the ground floor to store the temporary walls. The disadvantages is the use of technical handling to make the walls coming down. The biggest problem designing this method is when you actually don't need the walls during the sport activities you need the full height. This will cause a lot of trouble.

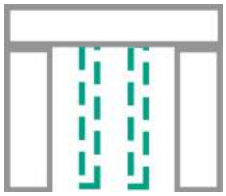
Rotatable

The solution to make rotatable walls is only interesting for the façade. The disadvantage is the impossibility of the adding of extra walls in the middle of the open plan. This limits the possibilities of the floor plan a lot. And therefore this could only be a solution for a flexible facade to open up to the community.



Shift

Last solution for this problem is to shift the walls. This has some advantages. When in static position they don't need a lot of extra space. Besides this there is lot of freedom in design, as you can place the shifting walls on several axis to make a lot of different configurations. The disadvantage are all the rails you need to make the walls shift and during sports games this could lead to problems. To solve this a system to click the walls into the floor or fix it at the wall should be designed. Further elaboration is needed when this method turns out to be the best.



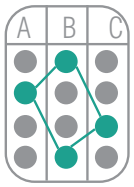


Figure3.4.31 Storefront Steven Holl(Fehrenbacher,2007)

Figure3.4.32 Moving gallery panels (Pinterest)

Figure3.4.33 Guillotine window (Vitrosca)

Figure3.4.34 Rotating window (Vitrosca)

Figure3.4.35 Sliding window(Vitrosca)

Alternative selection of the replacement of elements

In the scheme you can see that the shiftable element is the most promising alternative. There are three main reasons:

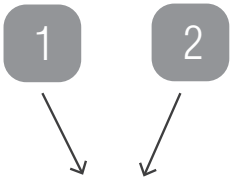
1. It is the most adaptable solution to make a lot of different configurations for the floor plan
2. Easy and lightweight method to control by users themselves
3. Can grow with the residents changing needs with ease

Replacement		Foldable	Moveable	Up & Down	Rotate	Shift
Ergonomics	2	7	5	5	7	7
Different elements	1	3	3	5	5	5
Adaptability	3	5	9	7	5	9
Flexible contact	2	5	7	7	7	7
Open surrounding	1	3	5	5	3	5
Self management	3	9	7	7	9	9
Grow	3	5	9	7	5	9
Total score		37	45	43	41	50

Figure3.4.36 Alternative selection replacement of elements (Own Illus.)

3.5 Alternative selection and concept comparison

3.5.1 Concept comparison of Step 1



For step 1 the scheme below shows the two different concepts that came from the comparison from all the different solutions. The two different concepts will be further elaborated and a decision will be made on which one of the concepts will be best to use.

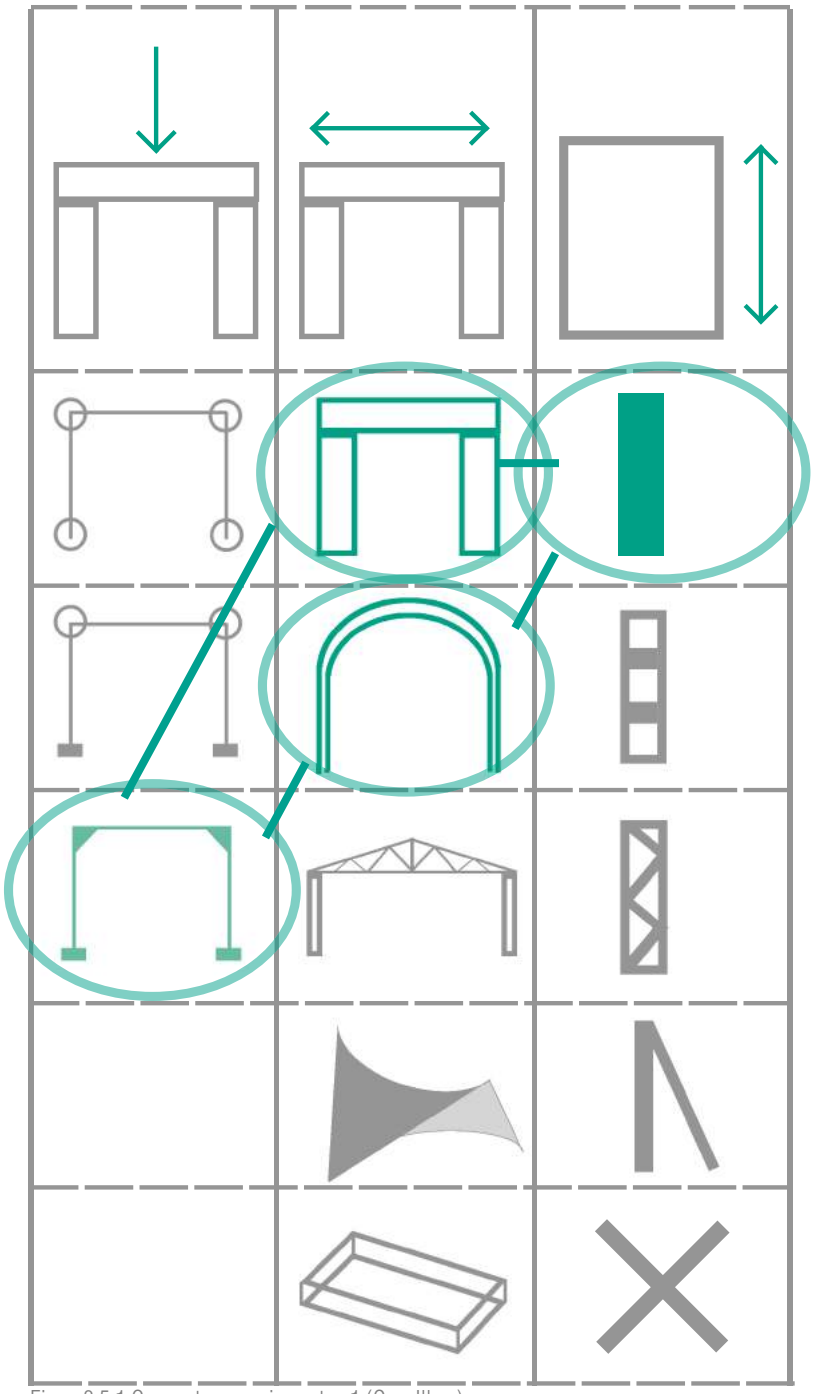


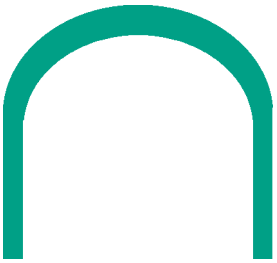
Figure3.5.1 Concept comparison step 1 (Own Illus.)

Concept 1:

This concept of beams and columns will be the most economical one. As the use of Baubuche can be used in this concept. Next to this the concept is also the most easy of the two as the beams have a basic form and therefore are easy to produce with CNC milling techniques. Next to this there is still a lot of freedom in designing the community center.

Concept 2

In this concept there is a lot freedom in design as well. The advantage of this method is that the beams and columns are one and can be placed at once. The advantage is also its disadvantage to produce such a big arch because more difficult techniques then with the first concept are needed to fulfill the job. Therefore concept 1 is more applicable for this project. As the ease of the production and assembly is key in this case.



Concept proposal step 1: Solid beam and column construction

The concept proposal for the construction principle results in a simple beam construction with solid columns underneath. This relatively simple constructions has the big advantage of freedom for the flexible building system to fit within this construction. Next to freedom of design it is also very easy to construct by a CNC-milling machine and easily assembled. Therefore this solution is the best concept proposal for now, further tests will show if this is the case.

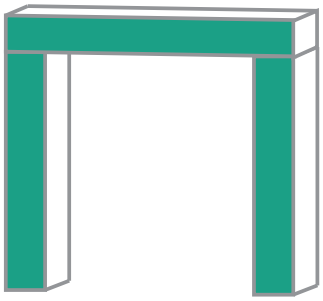


Figure3.5.2 Concept proposal step 1 (Own Illus.)

3.5.2 Concept comparison of Step 2

For the first part of step 2, a flexible building system, four different combinations will be examined. The concepts are drawn as floor plans. After this examination a first final concept can be chosen.

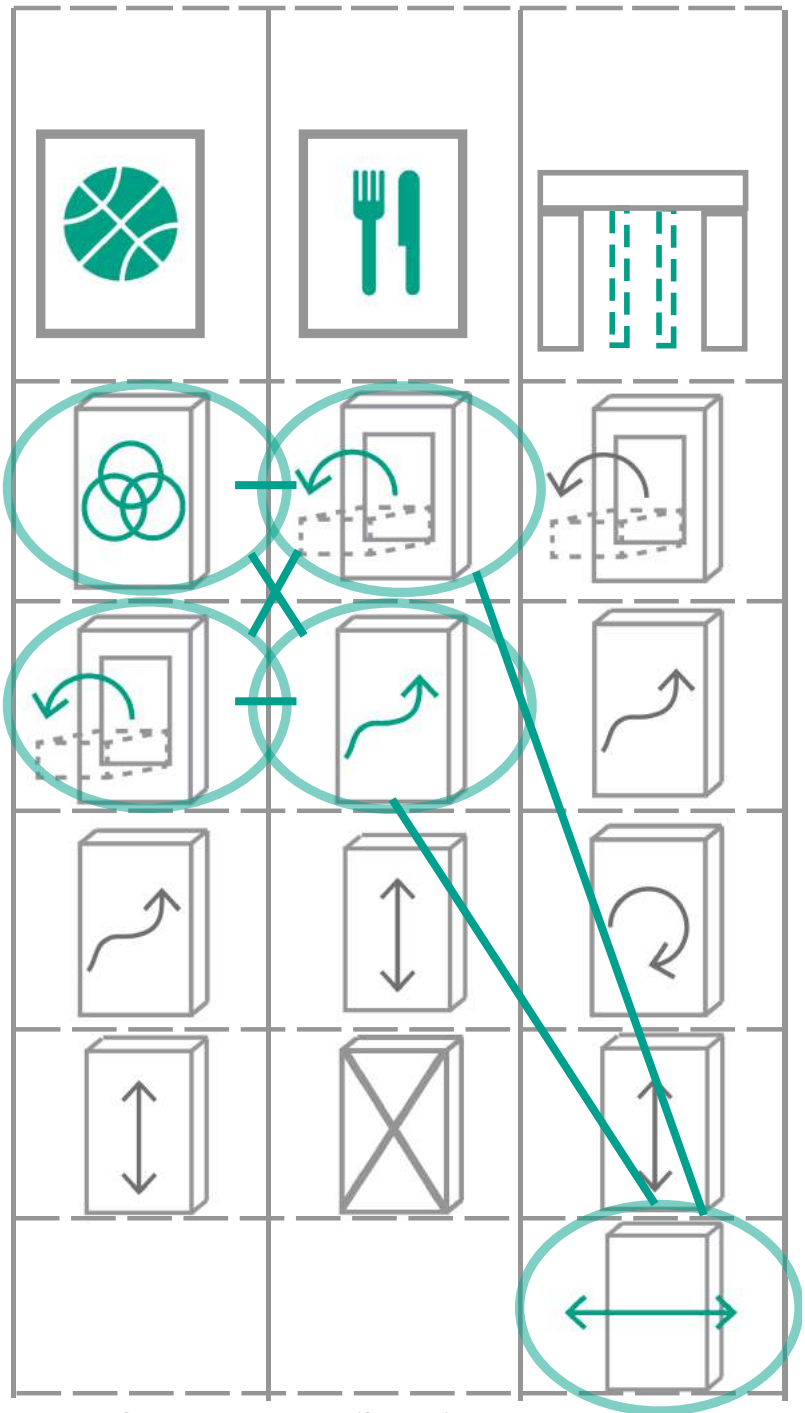
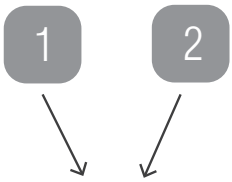


Figure3.5.3 Concept comparison step 2 (Own Illus.)



Concept 1:

This concept is ideal as the multi-functional wall can store everything and the foldable fixed elements that can be opened when needed with ease.

Concept 2

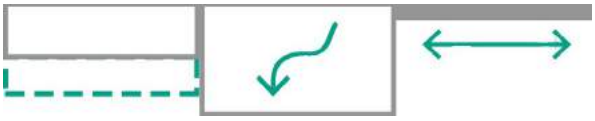
The tricky part in this concept is the moving fixed functions. After further elaboration it will make the building system to difficult if all the electrical and drains have to be flexible. Therefore this concept is not the final one.

Concept 3

In this concept both equipment and fixed functions are foldable. For the production of the building system this could be an advantage as the same joints and almost the same system can be used. But after further study the multi-functional use of the wall will be more efficient than the foldable wall. As there is many little equipment that needs storage and can't be foldable. In the end the foldable element is too limited.

Concept 4

As mentioned in concept 2 this concept is also too difficult because of the moving fixed functions. The system has to be as easy as possible in use.



Concept proposal step 2: Multi-functional element in combination with foldable fixed elements and shifting walls

An simple 3D scheme shows the concept proposal for the flexible building system. There are three main elements that are all adaptable in their own way, by being multi-functional, foldable or shiftable around the whole floor plan. This results in a system that can results in different configurations in the community center. They have in common that they all are very easy to handle for the users and contain the maximum adaptability. Further tests have to figure out if the system bumbs into any problems when integrated with the construction principle.

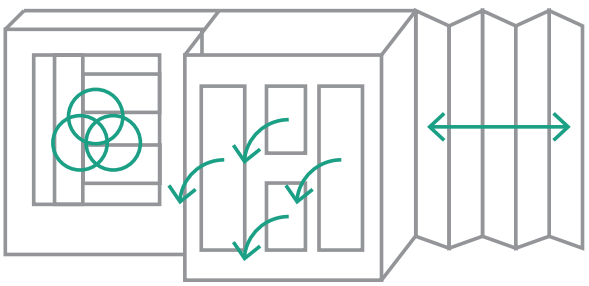


Figure3.5.4 Concept proposal step 2 (Own Illus.)

4.Conclusion and discussion

My research question was:

How to design a building system that can adapt to the changing needs of the permitted refugees and residents in an bio-based and CNC fabricated manner?

To answer this question the Quality Function Deployment method is used to come to a final concept proposal in a more objective way instead of subjective process. This concept proposal resulted in a simple solid beam and column construction principle in combination with an adaptable building system, containing three different part that are all adaptable in its own way. The equipment storage element resulted in a wall system that is multi-functional, whereby everything can be stored in an economical way in the wall. Therefore it will be easy to grab the right tools for the specific function. The fixed function element resulted in a fixed element with foldable walls. The advantage of this method next to its flexibility is its smart use of space. There is less space needed to place the fixed elements in the building. Last but not least there are the replaceable elements resulting in shifting walls who will be able to move in all directions.

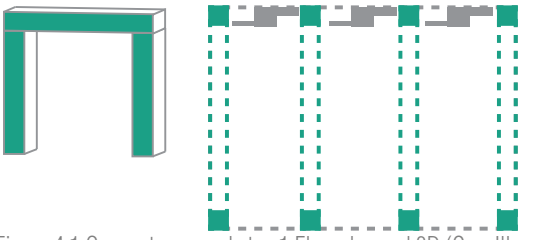


Figure 4.1 Concept proposal step 1 Floorplan and 3D (Own Illus.)

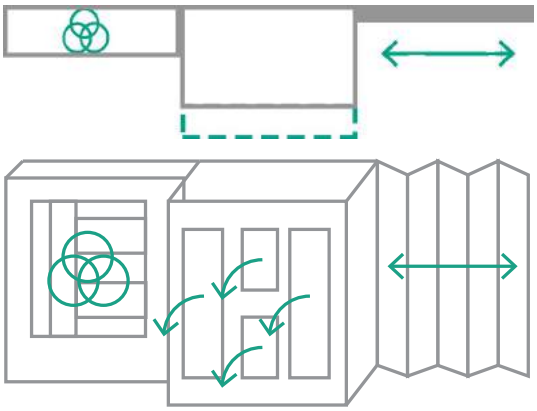


Figure 4.2 Concept proposal step 2 Floorplan and 3D (Own Illus.)

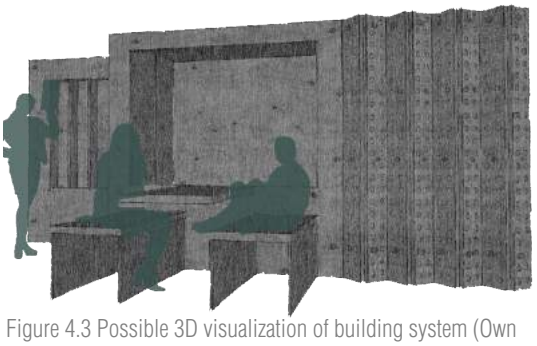


Figure 4.3 Possible 3D visualization of building system (Own Illus.)

The method used to come to this final concept proposal was very useful, it helped to look at the soft criteria in an systematic and objective way. It is quite hard to come up with the right criteria based on the users needs. The problem with creating the criteria was to set the aim, because the softer the criteria the harder it gets to set a specific aim. For the soft user criteria it was not possible to find a hard aim in type of numbers or values, but the aims where set in a more broad way. Still by making the ambition clear it was possible to set a harder aim then expected. The disadvantage of connecting a hard aim to a soft criteria is that you are not a 100% sure the aim you set is true. As no surveys have proven its right. In the end this method has been used as objective as possible, because when the aim is set very presice you can make a good objective alternative selection and concept comparison. Especially the concept comparison who was divided in three different parts for step 2 helped out a lot. If you have too many concepts to overview it is impossible to choose the right one. So therefore it was ideal that the concept can grow step by step.

Next step is to add more design problems into the building system. This can be done after this research. As this method has proven to work, it will be way more easy to let the concept proposal grow even further with adding extra solutions of other design problems. The only obstacle that has to be taken into account is whether the evolved concept proposal survives the test or fails and many problems will come up. If too many problems come up another concept should be chosen and tested untill all the problems are removed. This is going to be an interesting phase of the method and will be done in the designing phase.

Discussion

This method is definitely a good working method to make an architectural design question less subjective. The only step where the method gets subjective is setting the ambition and aim for the softer criteria of the users. Therefore you could choose to conduct more user interviews and surveys. To make sure you stated the right ambition and aim for the user. The only problem with doing this is that you need a lot of participants to make this trustworthy.

An extra addition to the eight step method in this case could be to still integrate the surveys as a method to test the concept proposal. If the concept proposal is not widely excepted by the users problems will come up and the eventually the right solution will be created. Further research has to prove in what extend user surveys and interviews have impact on this research method and can be integrated into one of the eight steps of the method.

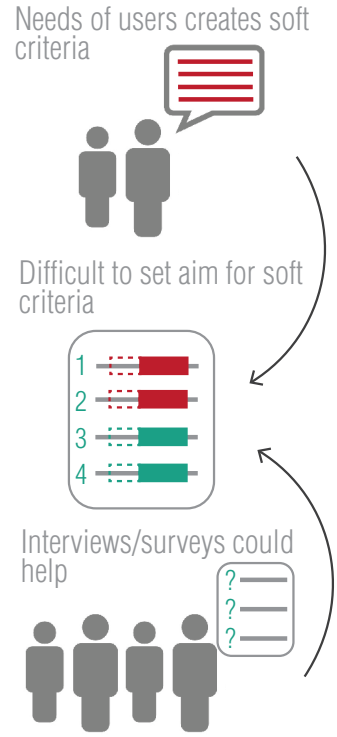


Figure 4.4 Recommendations for method (Own Illus.)

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6. Appendix

6.1 Location Analysis

Figure 6.1.1 Markets around the site (Own Illus. based on; City of Amsterdam)

Figure 6.1.2 Architectural expression of community facilities(Own Illus. based on; City of Amsterdam)

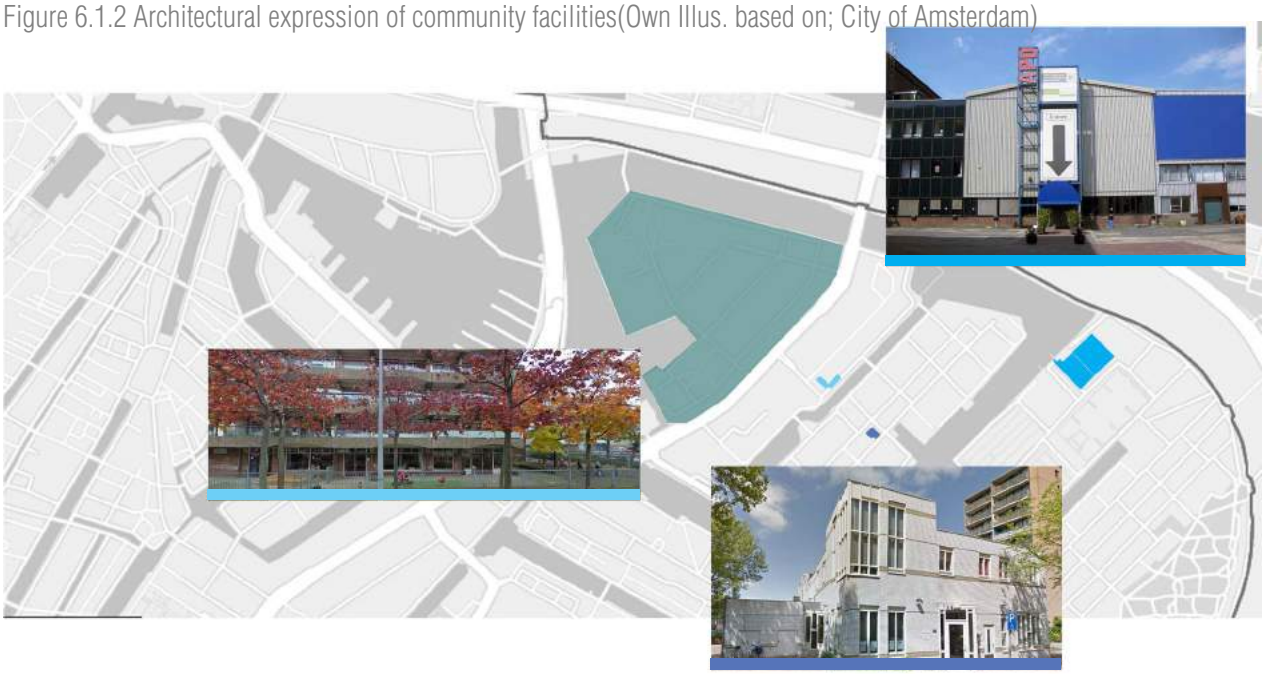


Figure 6.1.3 Sport facilities in the neighborhood(Own Illus. based on; City of Amsterdam)

6.2 Other design problems for the building system

Step 2

Climate

Acoustics: Sound absorption of architectural surfaces

For the building system acoustics are an important factor. For every function different acoustic requirements are required to have a nice acoustic climate. For example in sport halls a sound absorptive material capable of withstanding ball impact should be used above 3 meters (Culley,2016). There are a lot of different ways to make sure this acoustic climate will be obtained. Men can think of curtains and absorbent seatings which are flexible in usage. But the main problem is to make the walls and ceilings acoustic proof. This can be done by perforated panels, sound absorbing panels ore double leaf lightweight walls. The resonant panels and sound absorbing panels are designed for low frequency absorption of approximately 250Hz and are often used in music practice rooms. The lightweight separating walls can achieve good sound insulation values if the resonant frequency lie below the relevant noise spectrum(Egan,1988). All the different solutions will be well elaborated in the next step of this methodology.

Construction

Plumbing and electrical integration

Not only storage of equipment is a task for the building system, but an even more difficult task for the system will be the integration of plumbing and electrical support for all the different functions in the building. Especially when functions are moving around the building and need to have access to these supplies.

Placement of the components

One of the problems when defined how the components will be adaptable is to find out how to place the different components next to each other. This can be done in several ways and by choosing the most easy solution it will fit in the concept of making an easy building system.

Easy joints

Next to this it is very important that if some parts need to be moved and pushed or pulled apart easy joints are used. If unskilled labors are moving the building system no extra building knowledge is required to put it back together.

Architectural

Combine components

Another important criteria when the element's form is defined is how to combine the different components together. There are fixed components, more flexible storage components and flexible replacement components. All these different components need to be combined in an easy way.

Step 2: Further defining building system in Appendix

Make it sound proof and combine the elements

Details: joints, electrical

Figure 6.2.1 Design problems step 2(Own Illus.)

Step 3

Program

Open vs. closed plan changes

The combination of open en closed spaces is significant. Most consults will be small one on one sessions or in small private groups. But the network and job meetings will be done in bigger groups and can be more open. The rooms need to have some privacy with sound insulating walls, because somethimes private conversations will be held. For functions like the restaurant no privacy is needed and transparant space can be used when sport and culture classes are given. Of course the toilets, changing rooms and showers needs privacy. Therefore a good mixture of closed versus open 'elements' should be made for the building system.

Climate

Natural light and flexible lightning system

Lighting design for this community center will incorporate an daylight system, artificial system and control system.
For the daylight system several things have to be taken into account when designing the building. The position has to be correct so it will avoid glare, reflections, unwanted solar gain and heat loss (Culley,2016).
Regarding the artificial lightning this should be places ad a minimum height of 7,3 m. to not interfere with the indoor sports. Next to this ball games ask for lighting levels of at least 300 lux. Other functions like the office work need 250 lux and a restaurant need less lux, 150

(Engineertoolbox). To be able to react to the different functions the artificial lightning system should be able to be manually controllable in different color of lightning and illuminations. Another specific lightning requirement to take in mind is the fact that lightning should be positioned within a 4meter radius of a basketball basket(Culley,2016) .

Ventilation/Heating/Cooling

There are the normal criteria of a building regarding the ventilation like the control of humidity levels and adequate quantities of fresh air for building users. When the building has it's sport/dance function you should even better take into account the removal of impure air and odours. Especially when the class after you isn't intensive at all. Also the control of the temperature throughout the year with all those different functions will be more difficult. As it has to react very quickly to the changing circumstances. Also when a sports class take place it is important that the air movement in the playing zones is low, for instance in badminton classes this will be 0,1m./sec (Culley,2016).

Floor structure

The conditions of the floor play an important role during dance classes. It is ideal for the dancers to have a floor that absorb the shocks, for dance and indoor sports. Next to dance floors the sport hall floors are also specially made for demping the noise (Culley,2016).

Construction

Roof construction is able to open up

For the roof construction it should be taken into account that it is possible to open up parts of the roof. The configuration of the building could have private closed rooms with natural skylight coming from the top. The roof construction should be easy to open quickly if needed.

Existing foundation

Last but not least the building will be build upon an existing foundation of a sloped building. In this case it is interesting how to react on the fixed foundation grid with your building system structure.

Architectural

Open façade at three sides – open up for market, sport activities, restaurant

For the experience of the community centre it is important to open up the building to the outside space because the building is so multi-functional it needs to be opened up at three sides of the building. For sport events it is good to open up the building at two contrary sides so that athletic running games can take place, but also charity runs for the community. Next to this you want to open up the building at the longest side for the restaurant and events like theater or dance performance once in a while.

Enlarging the roof to open up building for market and create a covered area

Every week there will be a market and if the weather is nice it would be great if the building can open up to the market. Also with rain a part of the building could be opened and function like a roof for the square where the market takes place.

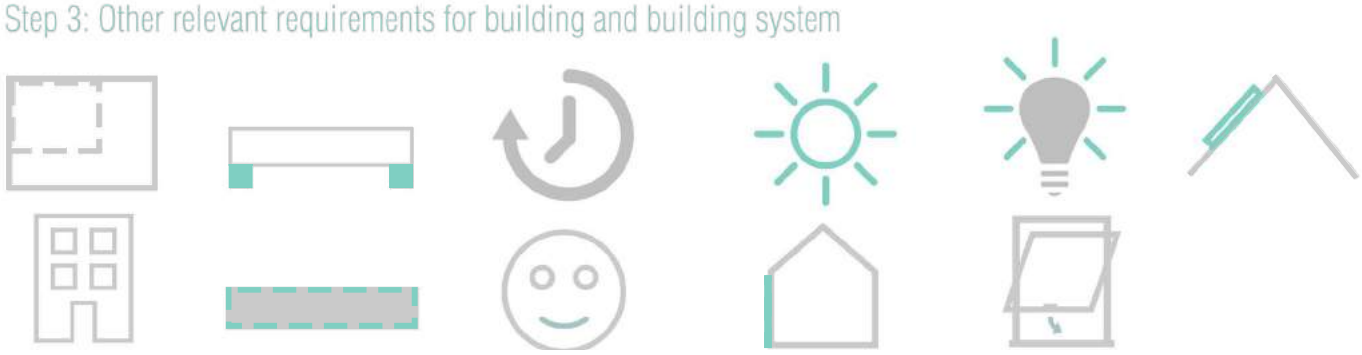
Experience of home coming feeling 'huiskamergevoel'

One of the more soft ambitions of my building system design is the fact that it has to feel like your own home. Like your comming home from work when you enter the door. I would like to creat as what the call it in Dutch an ´huiskamergevoel´.

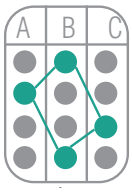
Appearance

Last but not least the appearance of the building is an important ambition. The look of the building has to be multicultural, this can be done in several ways. And therefore it is one of the criteria for all the ambitions, but it is also a design problem on its own, as there are several ways to design this multicultural experience.

Figure 6.2.2 Design problems step 3(Own Illus.)



6.3.1 Subresearch on CNC fabrication



Which CNC fabrication method should be used?

First a list of Digital fabrication that are possible to use for building construction purpose, after this a comparison is made.

Rapid procedures

The rapid procedures manufacture a physical 3D component in a short time without using any manual procedures on the basis of CAD data. In architecture this procedure is often used for the fast and cost efficient production of highly complex, individual and durable models, templates, prototypes and construction elements up to a maximum size of 1 by 1 by 1 meter. They are ideal for mass customizations.

CNC precast concrete

A CNC controlled robot will make a precast concrete elements within every special shape, opening. Individually segmented walls can be produced quickly and economically. It is 3,7 times faster than manually production. The procedure is limited to two dimensions because of the molding benches and place holders. The maximum size of the construction parts is limited to the transport sizes. It is an ideal procedure for mass customization.

3D printing

Free form constructions in large dimensions of 6 by 6 by 6 meters can be made without moults. The construction is very light, so it is easy assembled. The height of the construction is unrestricted and limited to the ability of the material to support its own weight.

Contour Crafting

Contour crafting is a comparable procedure. It is an extrusion procedure, which uses construction materials like plastic, cement or concrete, which cure quickly. In order to erect structurally stable walls the CC robot construct hollow walls and then fills it with concrete. A lost casing is created. In the future the result should be a quickly procedure to produce geometries without an expensive mold on site and without using manual labor(Karzel,2011).

Subtractive procedures

This method separated particles from the raw material so that the final volume of the construction part is reduced. They are able to realize individualized construction forms. But the question of material economy continually arises.

Laser cutting

Laser cutting is cutting material with a high energetic light beam. This is one of the thermal separation procedures. Laser cutting is suitable when the cut forms are complicated or vary within a series. A high level of economic efficiency can be reached. And the cutting edges don't need any follow up processing.

Water jet

The CNC jet cutting is used for 2D blank cutting of materials such as stone, metal or plastic. Doing this water is formed into a jet which comes out of a cutting jet at up to 1000m/s. The processing time increases exponentially with the thickness of the material. But the technology is able to cut irregular surfaces and don't need a specific focus point unlike laser cutting.

CNC milling

CNC milling is the processing of metals, wood or plastics by machining with a milling tool. Two dimensional objects can be milled easily from sheet goods. Disadvantages of the procedure are the slow processing speed, material waste caused by the milling head. With multi-axial mills the component part can be processed at unrestricted angels, which enables the production of 3D contours. Undercuts are difficult for the machines. CNC milling is the most variable of the subtractive procedures.

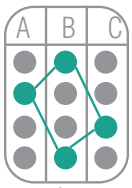
To find out what the best way of digital fabrication would be to make a flexible community centre I made a schedule. To choose the right digital fabrication method I set up five requirements for the technique. It should be able to handle bio-based materials, big sizes as told before, a high quality of cutting, of course 3D geometry and no toxic finish needed (Karzel,2011).

	Rapid procedures			Substractive procedures		
Digital procedures	CNC precast concrete	3D printing	Contour Crafting	Laser	Water jet	CNC Milling
Biobased material	-	-	-	+	+	+
Size	+++	+	+++	+++	++	+++
Finish needed	D	D	D	D	D	+++
Quality / precision	-	++	+	+++	++	+++
Geometry 3D	+	+	+	+	-	++
Accuracy	++	+++	-	++	+++	+++
Waste	-	-	-	+++	+++	+++

Figure 6.3.1 CNC Fabricaton comparison(Own Illus.)

As you can see yourself CNC Milling will be the best solution to make it easy to make a flexible building structure. This technique will be used while finding a solution for the problems I will be facing regarding my community center.

6.3.2 Subresearch on bio-based materials

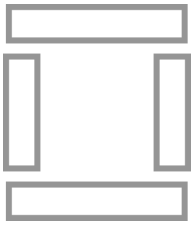


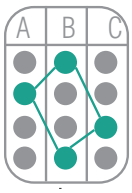
Eleni Sgouropoulou already sorted out some of the biodegradable materials in seven basic categories according to their source of production and use. The first five categories are materials that are already used as building materials and made by natural resources. The other two categories are more used in different sectors or are derived by new tech-nologies and still need development. This seven categories have 40 different kind of materials. But in this scheme the materials that are not local available and cannot be used for prefabrication to a building components. Twenty-four materials are left. The different kind of materials can be used for different purposes, some will function as insulation material, some as façade materials and some as the construction of the building(Ganotopoulou,2014).

Traditional	Earthen	Forestry	Farming	Agriculture	Mattress	New Technology
-Wood	-Limestone -Rammed earth -Cordwood -Adobe bricks -Compressed earth blocks -Clay dyes	-Papertubes -Papercrete -Paperstone	-Wool	-Hemp -Bamboo -Straw bale - Reed	-Horse hair -Seaweeds - Linen -Goose down	-Ingeo-corn fibres (insulation) -Canatex (fabric) -Zelfo(interior) -Batiplum feathers (insulation) -Mushroom (insulation/bricks) -Moniflex (façade)

Figure 6.3.2 Bio-based material scheme(Own Illus.)

6.3.3 Alternatives for the three following design problems to solve





Combining of components

As seen above there are three different components in the building system that need to be combined in a good way; the temporary walls, fixed functions and equipment storage elements. Five different solutions are made to solve this problem.

In between

First option is to fit the smallest component in between the bigger ones. The advantage of this option is the smooth finish. But to obtain this it would be more difficult to install. As the elements cannot be separately made and assembled on site. You will skilled people to construct the system.

In front

Next option is to place the wall in front of the elements. The big advantage for this option is the fact that it will not conflict with opening elements on the inside and is easy to install. The disadvantage that it has to be a more complex system of different sized panels to act like a wall inside the building.

Behind

You can twist this method around and place the wall behind the element. The advantage is the ease to make configurations inside the building. Next to this you are able to change the look of the façade in a simple way. The disadvantage is the extra space you need inside the building to house the temporary walls.

In front and behind

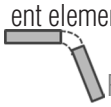
The combination of both worlds would be to put a bigger wall element that is in front and behind the elements. The advantage of this combination would be the endless possibilities with this method. What could result in a more flexible building system as the solutions before. As said before this method is very easy to install for unskilled people. The big disadvantage of this method is the fact that you need more material.

Adjacent

Last option is too place the wall adjacent to the element. This method will be more labor extensive. As the connection of the two elements has to be flawless with no air leakages. The advantage of this method is that it looks very smooth.

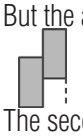
Placement of components

Next to making a connection of the three different elements a way of placing those elements on site needs to be figured out. There are four ways of placing the different elements next to each other.



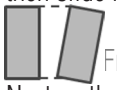
Rotate

The first method is to rotate the wall. The disadvantage of this method will be the fact that you need a big angle and therefore a lot of space to place every element. But the advantage is that it will be easy to install the elements.



Bottom to top

The second method is to put the wall from the top to the bottom and slide it at its right position. The disadvantage of this method is the fact that it has to be very precise to be able to fit. Also you will need extra tools to lift the element up and then slide it at the required position.

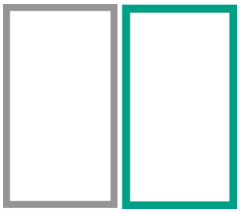


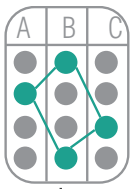
From the top down

Next method is to put it from the bottom to the top, so tilt the element into the right position. This could be easily done by two people, you only need a lot of men power as you have to tilt the element. You can only use this method if the composition of the components is adjacent or in between.

Sideways

Last option is to slide the elements into its position. This is by far the most easiest way of placing the different components and will not need a lot of power to place. It will only needs precision if placed in between or adjacent to each other, but if chosen to put it in front or behind it is even an easier method.





Acoustic walls

Natural wood panels – sound absorbing solution

One of the options is to put perforated panels on the wall. Of course there is lot of variety in these panels. Three different categories, describe the three different methods of wooden perforated panel. First of all there is the small perforated panels. With this method an NRC up to 1 can be achieved and the ambiance of the space will be maintained. This is the option with the fewest impact on the architectural expression of the building. Another option is the panel of planks. Here you can see clear vertical perforations. This method can be used with recycled wood and achieves up to NRC=0.9 and the ambiance of space with reflections at the highest frequencies (RPG Diffusor System).
Last one is the most expressive method with a varying design. The optimal binary pattern of perforations achieves a balance. These panels can also contribute undesirable acoustical effects based upon how they are perforated.

Planks - Diffusive walls

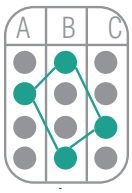
This solutions is an acoustical wood plank designed for high frequency sound diffusion. This method is the most applied sound diffusing plank, because rather than remove high frequency energy this solutions preserves that energy by uniformly distributing it back into the space. The onset of significant diffusion for the sound diffusive planks occurs at approximately 4000 Hz(RPG Diffusor System).

Wave - Diffusive walls

Next solution is the wave wall. The wave is a 2-part wood panel system, designed to blend the direct and reflected sound to increase intelligibility and enhance musical clarity and intimacy. A disadvantage is the fact that a minimum of 2 panel depths are required to achieve the best performance (RPG Diffusor System)..

Units - Diffusive walls

This method is already used since 1990 and can be found in churches schools and theatres. It is designed to provide an uniform sounds field through mid and high frequency diffusion while the wood construction of the unit limits the amount of sound energy that is removed by absorption. A disavantage is the dept of the units you need, a lot of extra space will be needed to store the temporary walls (RPG Diffusor System).



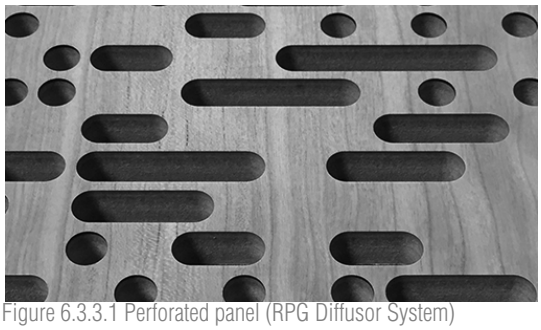


Figure 6.3.3.1 Perforated panel (RPG Diffusor System)

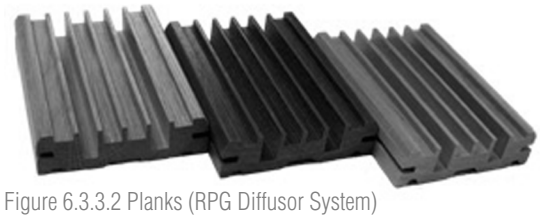


Figure 6.3.3.2 Planks (RPG Diffusor System)

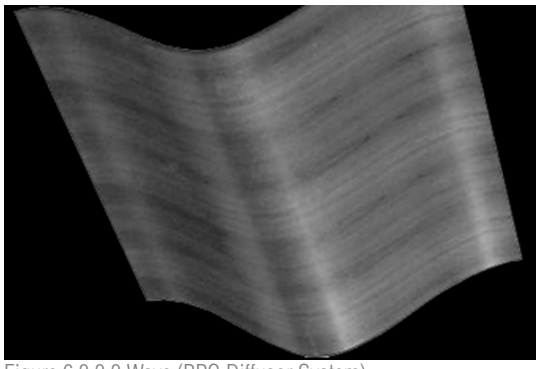


Figure 6.3.3.3 Wave (RPG Diffusor System)

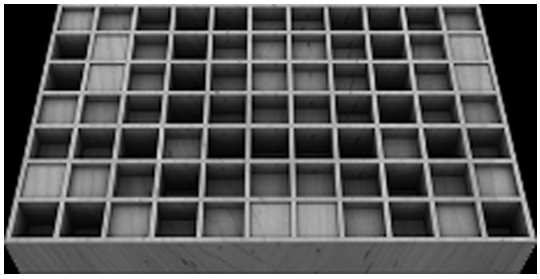


Figure 6.3.3.4 Units (RPG Diffusor System)