Paweł K. Kryński
st. no. 4521048
pe.krynski@gmail.com

research tutor:
Pieter Stoutjesdijk
architecture tutor:
Roel van de Pas

Delft University of Technology
Department of Architecture
Architectural Engineering
Graduation Studio

TU Delft

Architecture for Emergent Craftsmanship

Digitally manufactured customizable and reconfigurable workshops for makers

technical research paper
January 2017

abstract

This research aims to answer the needs of changing patterns of todays craftsmen and emergent maker movement, which is more and more visible after the mass production era and adapts to the post economical crysis world and to arrive with framework for a building design system. Interviews with craftsmen and visits at various workshops have been conducted in order to understand the needs and requirements of the target. In parallel, a study on mass customization and digital fabrication have been done. First - to provide the building system to be tailor made, while the latter is to pick the most suitable technology, which is easy to apply but the users themselves.

Results of this research are summarized by general profiles of makers and their detailed requirements, a mass customization mechanism that allows for meeting requirements of both singular maker and a collaboration and finally - a combination of digital manufacturing technology using CNC milling and fiberglass allowing for bigger scale structures. Application of this research is not limited to the craftsmen topic only; it can contribute to any study or design which touches digital fabrication and mass customization in big scale structures.

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Architecture of production in the light of new technologies

Architecture for production reminds usually of factories or workshops containing machines lined up into production lines with workers scattered around, robotically repeating the same simple actions. This doom picture of slavery looks terrible but fortunately it is not how it usually was and definitely – how it is going to be. With the technological advances like the irreplaceable computers and all production and processing control for which this machine allows, manufacturing takes a turn. But not only technical advances trigger this. Economy, as the indicator of all fluency in building industry and production has a tremendous impact also. These ingredients summed up reflect in architecture – a domain of all creative crafts which links finance, technology and art in a unique way, since the beginning of its existence.

Recent times pose a question: how can architecture for production respond to financial shortages and emergence of new technologies? Author of this thesis takes a certain position according to this topic: current form of architecture for production is a result of transformations following the next industrial revolutions. Recent shifts like the 3rd and 4th industrial revolutions did not meet many significant reactions echoing in architecture, even though working patterns of craftsmen changed and still evolve.

For architecture, Industry 4.0 means also an incomparable opportunity for improvement of design methods. That is presented by many graduation projects, research outcomes and realizations presented by many universities and architects of the world. However, even though design methods like parametric and smart design is evolving and still being developed, architects seem to fail in using it in the most important and effective ways. Formalistic approach takes over too often or on the other hand - academic experiments in sterile surroundings, which do not connect with real life issues like building law, tendering and therefore finance, or very down to earth factors like everyday use efficiency or fatigue. It can be inferred, that too often instead of being an extremely sufficient and promising tool it is treated as the aim of a design which in fact is capable only for being used in demonstrational pavilions or canopies.

While design methods often present vast areas of insufficiencies, fabrication is less intellectual but more practical. Thanks to the last improvements manufacturing is taken a completely different shape. On one hand factories can become more compact thanks to automation and optimization but on the other – there can be noticed a shift from large manufacturing compounds into small, scattered practices offering materialization of designs, available for everybody. An example of this could be Shapeways company, which offers their machines and 3D printing services.

According to Diez (2012) also a new phenomenon emerged – a Fab Lab – communal place which gathers makers and craftsmen side by side with hobbyists who want to use certain machines and share a workspace and cannot or do not want to purchase machines for themselves. Since the latter consociate many random users, they have to be accessible and located near the recipient, that means in the city centers or somewhere close.

Considering the historical legacy, the Fab Lab resembles the first stage of history of production – the ancient masters workshop which was situated in the city central part.

Technical advances are available also on the scale of a household. Small furniture sized or even desktop devices which allow for fine manufacturing of digitally designed items grows and gets cheaper. Wazer, which is a water jet – a device using high pressure water stream with a mixture of abrasive material, allows for cutting thick and hard materials like steel, stone, concrete or glass and compared to traditional water jets – does not cost an equivalent of a decent apartment . Ultimaker – an "out of the box" 3D printer which costs around €1000 brings plastic materialization of any object suiting its working bed limitations. It has to be mentioned that the cheapest printers oscillate around €200. Another technology coming home is presented by Shaper Origin – a CNC milling machine cutting wood and similar materials making any home workshop a carpentry ready manufacture.

Since there is an overload of standardized and mass produced goods, demand for custom and unique arose rapidly and is still getting higher (Lampel and Mintzberg, 1996). Amount of small creative companies rises and is about to take over the market, not only in the premium sector. Thanks to mass customization offered by new design techniques along with technology developments in the fields of digital manufacturing the two unrelated before worlds can be joined, not only by big players. Today, thanks to desktop 3D printers, water jets or CNC milling machines anyone can become a manufacturer of various goods. Production is democratized and accessible to everybody willing to dedicate a few hours of time to grasp the file to factory methods and buy relatively cheap machines.

On the other hand, the year 2008 brought to the world thrilling uncertainty. The US housing market, always taken as the foundation of the country's economy has plunged and led to the biggest financial crisis since the Great Depression in the 1930s (Eichengreen, O'Rourke). The building industry, as the most vulnerable to any market shakes was struck immediately nearly all over the Europe as well. Many architects and engineers lost their jobs. Also, usually when people experience any financial problems the first cuts on spending consider branches that are not crucial for surviving – like culture. Loads of artists lost their orders and contracts.

Because of that, new patterns of collaboration emerged and new working environments became popular, like never before. Those who lost their jobs had to take actions – a lot of them united and started working in collaborations, like architects, designers, craftsmen (Asselbergs, 2015). That meant sharing workspaces and supporting each other in different forms:

- emergence of co-working spaces;
- collaborations of one-man companies;
- mentioned before Fab Labs.

The first pattern has been created somewhere around 2006 although it was for the financial crisis to propel the co-working space popularity. The main idea is not to share finances and cooperate in tight business bonds. This pattern provides rather soft support like the fact that many people share the same space in pleasant relationships or have lunch together but also can pay less for renting a space.

The latter however, presents a tighter financial responsibility. They perform as a cooperative which can take orders both collectively and separately, depending on the complication level or size of an order. If, for example, the collaboration is supposed to design and produce an interior for a restaurant, they would pick the most suitable and experienced members and work together on the order. That way all members get more orders, have a higher income and do not have to count only on themselves and their clients – sometimes work comes from somebody else.

All of the patterns are about sharing, and the last of them – the Fab Lab – shares machines and knowledge. For some, Fab Labs are only a fun place to come but more often today – it is the collaborative workplace for professionals.

For today's manufacturing agents certain patterns are common for all. First example is that selling products shifted from physical stores to online. Moreover, because of the fact that production gets decentralized, democratized and scattered around many small production facilities also the ways of acquiring orders are changing and collaboration between agents is appearing. Networking is the key change of collaboration which helps to overcome financial cuts and exploit the market more efficiently. The fact that orders come from different sources and have different characters often means that each new project needs a unique approach. This approach is manifested by the setup of the workspace and area which is needed for realization, along with varying tools. Therefore it is often not needed to own the tools, but borrow them, lease or share. As for the workplace – the key feature is flexibility and reconfigurability, which are highly limited in traditional designs of workplaces and architecture for production.

Traditional approach seems to fail to meet the previously sketched requirements. Best proof for this lays in the current trend – collaborations of craftsmen, Fab Labs and co-working spaces which usually rent postindustrial halls which were designed to suit requirements from previous periods. Very seldom this architecture responds to flexibility and reconfigurability needed, and even if, it is mostly not thanks the design of the building but the extra amounts of underutilized space or reconfigurable furniture brought or made by tenants or features alike.

This part of this thesis presents the research questions which structured the whole work. Main question is overall and is divided into three subquestions, which touch three different topics.

research questions

overall research question

How to design a mass customized building system, housing workspaces for craftsmen, made by digital fabrication tools?

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sRQ 1:
- what are the needs of makers and craftsmen?
- how do they work and what environment do they need?
- is it possible to define profiles of makers and sort them to help with customization?

sRQ 2:
- how can a customizable system for workshops and apartaments answering all needs of makers and craftsmen be designed?

sRQ: 3
- what kind of technology should be used to design a customizable building system which is possible to be produced locally by makers themselves?

research subquestion

Research methods

From the three subquestions mentioned earlier derive three ingredients of this research.

Therefore the research will be conducted in three different topics. They will studied in parallel, although they will not be started in the same time, therefore the shift indicated in the diagram on the next page.
Even though the topics are conducted in parallel none of them will work separately because they feed each other constantly along the research.
For example, the requirements part feeds the customization part so that it is provided with data allowing to know what kind of customization is needed. First part also feed the last which is about digital fabrication so that certain sizes or volumes should be expected what will allow for adjusting technology research to that. And each of the following parts also provided feedback for the previous parts, thanks to that it was possible to adjust the ways of researching and drawing conclusions.

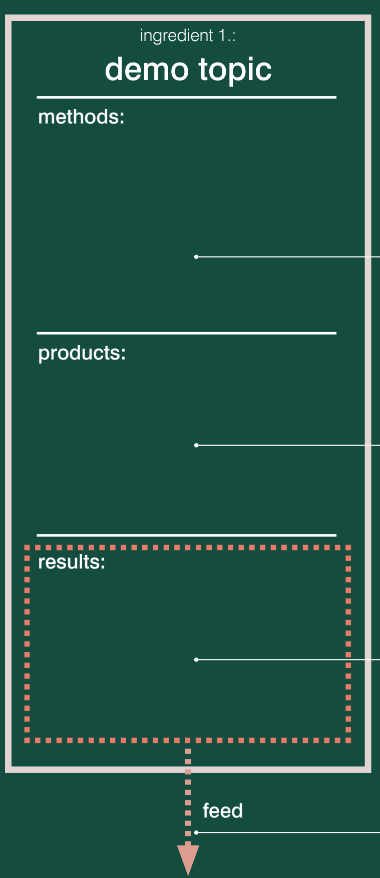
Research ingredients

Now the relevance and meaning of research ingredients will be explained.

1. Requirements Search
This part provides the research and the project with strict requirements obtained from potential clients, through extensive interviews and visits in their workshops. Thanks to this study it will be possible to understand how the clients work, and what are the prevailing trends in their methods of work and needs. This feed will be crucial to understand what is unique and needs to be customizable for each different client, and how.

2. Customization
This part will evaluate the needs and requirements distilled from the previous part of research. Apart from that, the point of this part is to thorougly study and understand methods and systems for customizability in recent developments. Thanks to this it will be possible to classify and define my need for customization and the level of involvement of the client in it. Also a sketch of features of the future project that need to be customizable and reconfigurable will be provided.

3. Digital Fabrication
The third part of the research will focus on digital fabrication in order to find the best technology and material combination for the upcoming design. Different techniques will be compared through literature and reference analysis. That will be gathered in a database which summarized will allow to pick materials and certain techniques acoording to results. Research on particular technologies and materials will be followed by hands on experiments.



Each part on the diagram is divided into 3 different parts. That is done mostly for the authors concenience and clearness of the process and also to clarify the research flow.

methods used to research - how was the topic studied and with what means?

products and delivarables - what will be delivered upon completion of this part of reseach

results will be concluded from the databases and will feed next part of the research and moreover - will feed the next stages of working on projects and feed any further research

the feed will be linked to both following and previous parts of research creating a contінous feedback loop

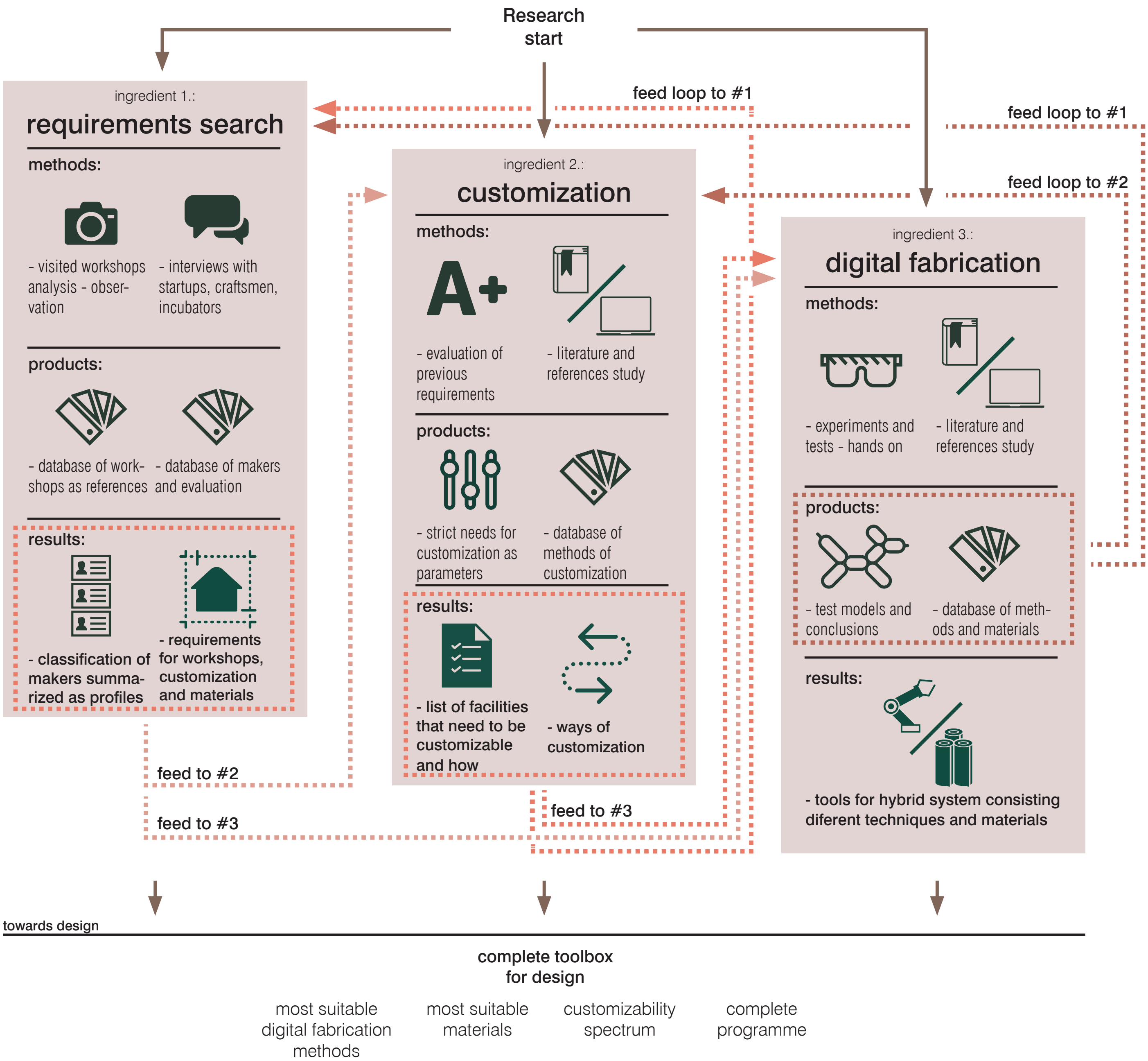


Fig. 1 - research method diagram (own illustration)

research methods diagram

1.00

requirements search

Research methodology
This chapter opens the research as it was also the first action taken along working on this project.

The author performed 15 interviews and visited over 20 workshops to understand the Makers movement. These talk took place in Delft as well as at the Dutch Design Week 2016, along with many telephone and videocalls.

All the knowlegde the author was able to obtain is gathered in Appendices 1 and 2 (p. 63 and 89). Conclusions drawn from these databases and this part of this research will be presented in the following chapter.

Results and conclusions

Comparison and juxtaposition of data of all interviewed makers (Appendix 1, p.63) allowed to notice certain patters and tendencies. There are trends typical for certain groups but also for all of them together. Thanks to this study different profiles of possible tenants were possible to define.

Five different profiles were distinguished:

Hm_{I}

Profile 1 - **One Man Hobby [Hm_{I}]**

Pc_{II}

Profile 2 - **One Man Professional in Collaboration [Pc_{II}]**

Sc_{III}

Profile 3 - **Small Company [Sc_{III}]**

Mc_{IV}

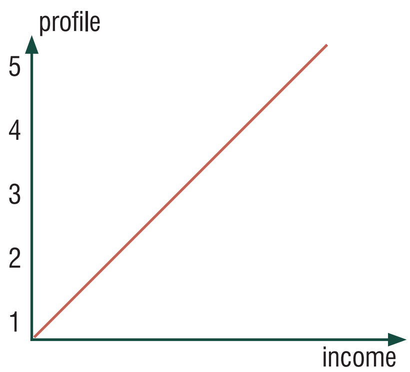
Profile 4 - **Medium Company of Makers [Mc_{IV}]**

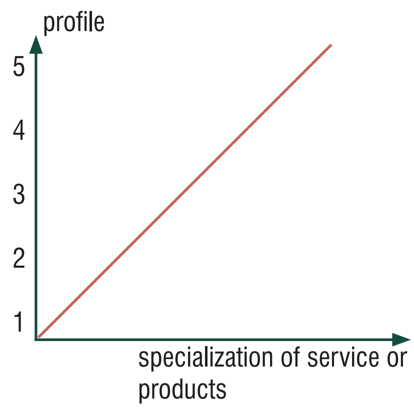
Pd_{V}

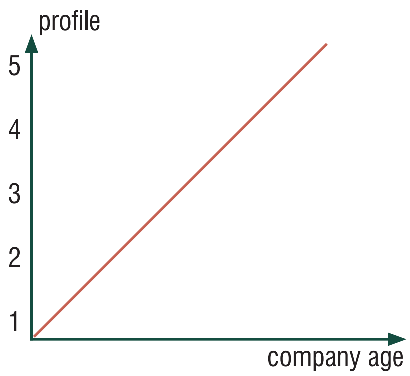
Profile 5 - **Medium Company of Product Developers [Pd_{V}]**

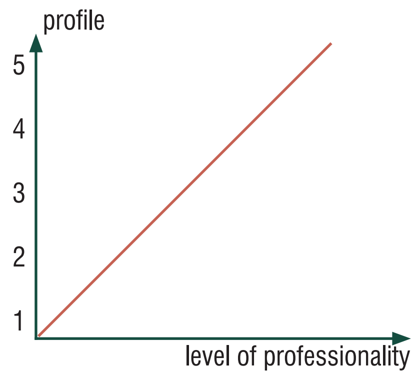
Knowing predefined profiles, with use of the second database (Appendix 2, p. 89) containing finishing comparison it is possible to predefine a model workshop for each profile. Each model workshop requirements use domains, what allows for several custom options for each profile. Thanks to this constraints it will be possible to tailor each workspace to the tenant.

Even though profiles have been specified, some common characeristics can be noticed, applicable for makers and their workshops.









Some companies don't follow this trends - like the hobby ones. For example, Buttonius is a quite old company, but because of lack of effort (and need) it is not expanded or developed into anything bigger. Another common trend is that none of these companies has a sigular activity of business. Of course, higher profiles are specialized in a certain branch but still their products and services operate in a certain domain.
The lower is the profile, the wider is the domain. A comparison of Tjielp Design and The New Makers will help to show that.Tjielp, which is a profile 1, produces items like jewelry but also interior designs. These branches are quite far from each other and use completely diferrent rules and constraints. The New Makers, on the other hand, is a profile 4. TNM makes items from furniture to cabins, but with the exact same technology and materials. Only because of their technology they are able to apply it for different needs.

Common characteristics can be distinguished for all workshops:

Daylight
D. is preferred in all cases even though not every workshop in my study had it. This is mostly a result of the fact that companies often rent places that had diferrent funtions before so they have to reuse and adapt them. That means their workplaces are not tailored to their needs and 100% of entrepreneurs that I talked to or investigated had to adapt their ways work working to their workplaces, not the oposite.

Flexibility
F. of each workplace was crucial and often fundamental. Solutions like modules of workshop equipped with wheels allowing to reconfigure the setup is a very inspirational feature, and was noticed in The New Makers workshop. Most makers admit, that each new project changes the workshop or its setup in some way.

Distance to machines
Every company confirms that being close to machines is highly important, apart from products developers group who only have a rapid prototyping room well connected to their design office, but they are not "makers" in particular.

Selling online
Most of the groups, except III, sell their products only online and don't need any shop space. In some cases a small showroom is required.

Machines
Only collaborations like Collaboration-O or bigger companies like The New Makers can afford to own more sophisticated, professional machines. That is a result of high prices of machines which are catalized with additional technical appliances that these require, and high energy consumption.

The following part will be present the characteristicts of the makers profiles.
It shows common, non numerical characteristicts which help the reader to understand the profile while the data in the charts will feed the following research ingredients (the #2 and the #3) with specific numerical data and limitations. But not only this research, these data may serve as framework for any design for craftsmen.
The numerical data and strict parameters in detail are gathered in Appendix 3, p. 145.

Hm$_I$

One Man Hobby

common characteristics:

- hobby like activity and approach to business - not the main source of income for this person
- one man business
- working alone, not collaborating with anybody, sometimes organizes workshops for friends but rather just for fun
- not many clients or orders, because of that the income is too low for them to fulfill financial needs of a household or a person
- limited amount of machines and types of machines
- products are not sold on place of work but shipped to customers

not common characteristics:

- machines are owned but sometimes shared, when certain maker uses services of a fablab
- one or many fields of expertise

examples:
Buttonius
Tjielp Design
Full Bush Design

Pc$_{II}$

One Man Professional in Collaboration

common characteristics:

- professional activity - main source of income
- one man company
- working in collaboration and dependant on them
- bigger number of machines and types of machines, which are expensive, so they have to share costs of them
- not many orders - collaboration allows them to take bigger orders as a one entity and work on them together
- bigger space is needed because of wide variety of activities

not common characteristics:

- selling on space
- size of products
- size of storage

examples:
Sander Wassink
Joan Velve Raffecas
Ben Hohmann
Joost Gehem Designs
Kim Haagen Studio
Coradino Garofalo
Transfodesign*

*even though Tranfodesign is not a one man company, their activity and common characteristicts suit this profile the most. The fact that they work in 3 people team is the only diferrence from other companies in this group.

Sc$_{III}$

Small Company

common characteristics:

- professional activity - main source of income
- up to 8 employees
- independent company
- very specialized products
- many orders and clients
- not many machine types, but a lot of single type copies
- specificly defined target buyer or customer
- flexible space, ready to be expanded

not common characteristics:

- size of products
- additional services or activities, like leasing machines or workshops or design

examples:
M-Edelsmeden + design
Atelier Indrukwekkend
Laserbeest

Mc_{IV}

Medium Company of Makers

common characteristics:

- company specialized in complex designs and producing them
- a lot of orders - 10 weekly
- >8 employees
- company works on multiple projects simultaneously
- big area demand for workspace and advances technical appliances needed
- small number of machine types but very advanced ones, industrial top notch
- products are big sized and affect working space, need special logistics or vehicles to be moved
- workshop has a supply chain structure, demands a sepa-rate design

not common characteristics:

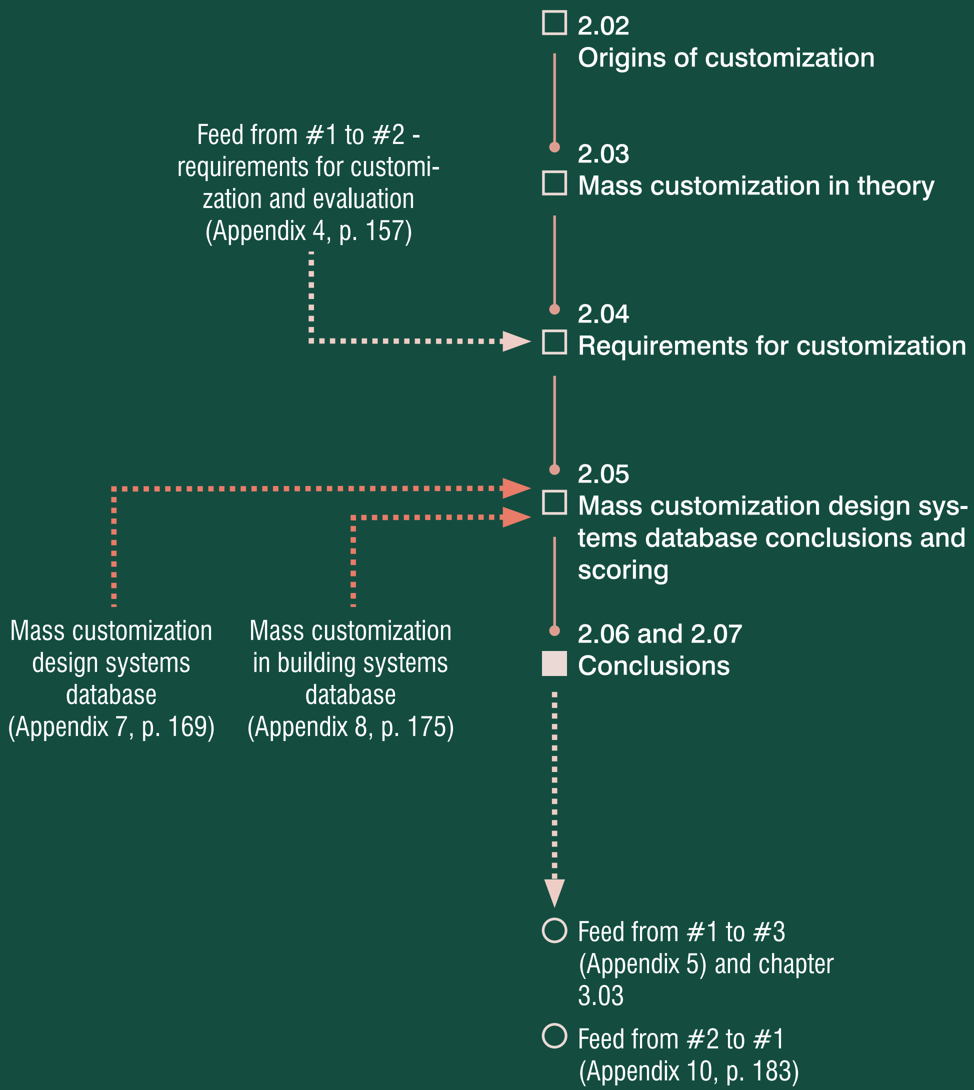
- additional services
- storage size

examples:
The New Makers
WikihouseNL
Spidersigns

2.00

customization

2.01 chapter sequence



2.02 Origins of customization

Production patterns development

Todays production line is affected by hundreds of years of evolution. Along with enchantment to beautiful products and items crafst have been developed from centuries and were always appreciated by those who could afford it.

The first recognizable pattern developed in ancient times and endured for a long time. Often with help of patronage, creators were locked in their workshops which were unique and misterious wonder worlds. Craftsmen worked alone or with help of their apprentices.

First significant changes were imminent with the invention of the steam machine. That started the 1st Industrial Revolution in the beginning of the XIX century in Brittain which shifted hand made production into extensive machine use. Along with this, new chemical manufacturing and iron works were developed, water use has been extended and the factory term have risen. Immense changes to society and the image of cities were imposed suddenly, what had a tremendous impact on people's life.

Another step in this history was the 2nd Industrial Revolution which took place in the beginning of the XX century thanks to Henry Ford, who introduced the production line term and mass production. At this point the issue of customization was noticed as mass production disabled people from having personalized products like before Henry Ford's improvement. Because of the overwhelming standardization all the features that defined it's personal character were removed. That production pattern is prevailling till today although it started counter - movements and different patterns of custimization.

As mass production presents a vast amount of insuffieciencies and unefffectiveness other patterns were created. One of those lifted Toyota into top shelf or car producers. Lean Production also known as Toyota Production System were ceated to reduce these unefficiencies. One way of reducing those was the JIT method - just in time, which lowers the need for storage area as the production is taking place only when an order is placed. JIT increases customization as customers satisfaction is not dependant on exsisting stocks anymore. Lean production employs small teams of specialized workers clustered around the product and perform desired operations, like pit stop teams in Formula 1. Because of less repetitve actions taken by workers their creativity and awareness is higher as well as motivation. And most important of all - assebly line is redundant, compared to traditional mass production.

This system aims to reduce waste in different aspects which is present in mass production defined by Shigeo Shingo as seven *mudas*:

- transport - movement of products that is not required in the production process
- inventory - components that are finished but not further processed
- motion - all movement of workers or gear that is not required in the production process
- waiting - waiting for the following production step or lags during shift changes
- overproduction - production ahead of demand
- overprocessing - poorly designed product result
- defects - and all effort involved in fixing errors

and also defined later in 2003 by Womack et al.:

- manufactured goods that do not meet clients requirements.

Another turn in the history of production took place with the popularization of computer and emerging from that numerical controlled machines. Further automation of production is achieved thanks to electronics and IT. With the first Programmable Logic Controller (Modicon 084) from 1969 customization and mass customization became possible, even though is was not yet known in the form as it is today.

Last part of the development of production is the Industry 4.0 which integrates cyber - physical production systems. Even though the patterns are still being developed and not etirely introduced to real life and available for common, the aim is to determine how and when producers manufacture their products according to clients input. Information and communication technology (ICT) along with smart automation enable integration of embedded manufacture processes what creates intelligent, decentralized, object oriented models which evolve to cyber - physical design and simulation by using intelligent software.
An example of usage of this shift is Michellin - a tyre manufacturer. Thanks to smart sensors embedding technology this company added a service to their portfolio - safety and mobility of tyres. Problems and errors are adressed based on feed from the intelligent network of sensors built-in to their highest models of products.

The history of production makes a circle. From highly personalized handmade objects made by masters who spend their lives on accomplishing a few orders taking their lifetimes, through completely impersonal mass production system, where each item is born on an assembly line we finally arrive at a point where customizability is again possible and in value. Although input is taken from all ingredients of the story and finishes with both repetition and individuality - mass customization.

2.03 Mass customization in theory

M. C. is a combination of two systems that provide both low cost and repetiveness thanks to mass production with flexibility of custom manufacturing. (Duarte and Benros 2009). Achieved often with means of computer aided design (CAD) and computer aided manufacturing (CAM) allows for bridging the gap between mass production and personalization of products.

Mass customization however is a vast topic and needs to be clarified. In order to understand what kind of mass customization and what kind of clients influence is desired a classification has to be performed.

2.031 Marketing

	marketed	not marketed
standardized	Cosmetic	Adaptive
customized	Collaborative	Transparent

Pine II (1993) defines 4 types of mass customization and weather producers advertise those as custom or not:

Adaptive Customization - that type of customization takes into account a standardized product with features allowing for customization. As an example can serve a bicycle - with adjustment of seatpost height and handlebars the product is being customized accordingly to users needs. The products is very typical and is not sold as a customizable;

Cosmetic Customization - products are marketed as customized specially for a certain target audience, even though they are standardized and mass produced;

Transparent Customization - in this case a customized product is marketed as standard. An item, which in fact differs because of various reasons is sold as standard and comes under the same name od brand;

Collaborative Customization - this approach takes communication of customer and producer in order to satisfy clients needs. Feedback from client is used when manufacturing - as an example can serve a kitchen set where the customer specifies exact dimensions and parameters of his favourite kitchen setup which are then processed in the factory. In this case the product is marketed as customizable;

The last mentioned approach is obviously what building industry is looking for, and what is used more and more commonly in all industries, especially with the incomming Industry 4.0, Internet of Things etc.

2.032 Involvement of the client in production process

Another division of customization takes into consideration the level of clients involvement into the process. According to “Customizing Customization” (Lampel and Mintzberg, 1996) there are 5 stages of letting the client affect the production:

Pure Standardization - the only customization is provided of the product has such a feature, but the client is not introduced into the process at all;

Segmented Standardization - in this case the client has influence on the distribution part of the process, changing the delivery schedule or place, etc.;

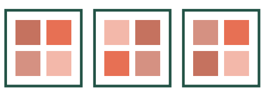
Customized Standardization also known as Modular Customization - is when the clients enters the production in the assebly phase. This is applicable to a single product as well as to a whole family where similar components are shared and compose a working unit. It could be explained as a platform based customization, as an example could be cited the modular smartphone concept - Project ARA developed by Google and Motorola. Client could choose from 3 sizes of frame and fill them with variety of features like different cameras, CPUs, memories, readers and sensors;

Tailored Customization - here the client is involved from the manufacturing phase onwards, products are made from predefined materials but accordingly to needs;

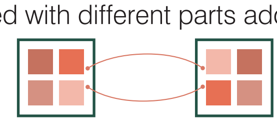
Pure Customization - in this case the customer is involved from the very beginning of the process i.e. from the design phase. A good example is vernacular architecture, single houses in particular, when the design is tailored and depends mostly on the investors will and needs.

2.033 Modularity division

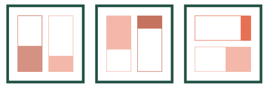
The modular approach, mentioned in Customized Standardization method before can have different methods of realization. According to Duray et al. (2000) these ways present as following:



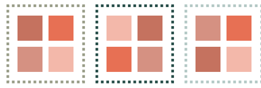
Component sharing modularity is when a series of products share the same component, for example a desktop motherboard, which is unified and equipped with slots to be combined with different parts added;



Component swapping modularity is a case when certain components can be swapped and replaced with others without changing the turnout of the whole product. As an example serves a desktop computer again - we can swap RAM modules, CPUs or hard drives;

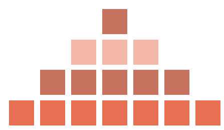


Cut-to-fit modularity allows for changes in parameters of certain parts of a product without changing the turnout of it;



Mix modularity reminds of component swapping modularity however here the final product does not remain unchanged. As an example can serve Google Ara smartphone, where depending on installed modules the device has different colors and textures what allows for unique design and visual personalization;

Bus modularity allows to add a similar module to an existing series;



Section modularity is allowing for a different approach - it is similar to systems used in building industry, when standardized elements are used to assembly unique products.

2.034 Involvement of the client in design process

An division of customers influence into the design process will be now presented. This can be treated as an extension of the last option from the previous part - Pure Customization - is provided by Alford et al. (2000). He distinguishes three different approaches:

Core Customization - client has a high level of influence on the design as the product operates in a specialized niche and is directed to a specific client who covers a significant amount of orders for this product;

Optional Customization - this case is present when certain amount of options is provided to satisfy needs of multiple clients;

Form Customization - small modifications of certain products such as additional options in yachts configurations. ■

In the following part of this chapter, methodologies mentioned in design systems database (Appendix 6, p. 165) will be evaluated upon previously formed requirements. Before that will be done, relevance of certain requirements will be elaborated. All the requirements have their weights calculated in Appendix 4, p. 157.

1 reconfiguration potential (III)
Additional value (as not all customization systems have that and it is mostly depending on the building technology) that makes the system ready for any reconfiguration in future, following the final assembly. That requirement results from the need for constant changes in the workshops and overall flexibility of the setting.

2 modular friendly (III)
Ability to operate in modular solutions, for example as elements that are able to compose bigger bodies composing a stock of items which are standardized and compatible to each other in some way. That allows for exchanging modules between users and share them improving reconfiguration potential both on personal and collaborative levels.

3 open source (II)
Modifiable design method for the user. Flexible enough and easy to understand in order to be implemented differently from the initial version, according to user needs. That allows to invite user to control the system and influence it.

4 user influence (II)
Scale of users contribution into the design.

5 depth of customization (II)
Scale of adaptability of particular elements of the design according to user needs.

6 design freedom (I)
Ability to compose and construct multiple options and functions of a product using particular design method.

7 efficiency of combinations (I)
The limitations of combinations and relations between them. Value of combinations and effort of the designer to provide tailor-made solutions for customers. For example: the fact that a system provides endless combinations is not a benefit if it is confusing the client or making the system complicated and requires additional tools to be controllable.

1. Sears prefabricated houses

1 reconfiguration potential (III)	□□□□
2 modular friendly (III)	■□□□
3 open source (II)	■■□□
4 user influence (II)	■■■■
5 depth of customization (II)	■■■■
6 design freedom (I)	■■■■
7 efficiency of combinations (I)	■□□□

Sears prefabricated houses is a catalogue solution which can be impressive even after a century. However, this solution offerred only fixed houses which could not be reconfigured. Modularity of this solution is also limited as well as efficiency of combinations. Considering the heavy user influence, depth of customization and broad design freedom this system is very inspiring even though it is not treated by the author as any possible solution considering this research.

final score **2.00**/4

2. Shape grammars

1 reconfiguration potential (III)	□□□□
2 modular friendly (III)	■■■□
3 open source (II)	□□□□
4 user influence (II)	■■■■
5 depth of customization (II)	■■□□
6 design freedom (I)	■■□□
7 efficiency of combinations (I)	■□□□

Application of this system is diffucult (Knight, 1992) and cumbersome when it comes to implementing abstract forms into any design. Apart from that, it offers vast variety of iterations, which is overwhelming when presented to a simple client, who is interested in housing, not a mathematical phenomenon which do not directly provide any profit. What is more, shape grammars are difficult and time consuming to implement into any sofware as they need linking shape recognition and rule aplication.
In cace of this research there is a certain number of parameters that are quite the same initially. What is crucial is the customizability that comes with time which allows for flexibility and reconfigurability rather than and endless amount of iterations and variations.

final score **1.71**/4

3. Panellized kit approach (FlatPak)

1 reconfiguration potential (III)	□□□□
2 modular friendly (III)	■■■■
3 open source (II)	■□□□
4 user influence (II)	□□□□
5 depth of customization (II)	□□□□
6 design freedom (I)	■□□□
7 efficiency of combinations (I)	■■■□

FlatPak solution presents a quite limited customization method. It allows only for customization of the finishes and outer shell of the building, while the crucial elements remain unchanged. Zero reconfiguration potencial and lack of open source access also lowers the attractiveness. User influence is also very poor as well as depth of customization - those result from the pool of customizable parts. What is good though, is the modularity and thus ease of installation and efficiency of combination, thanks to that.

final score **1.57**/4

4. Component approach

1 reconfiguration potential (III)
2 modular friendly (III)
3 open source (II)
4 user influence (II)
5 depth of customization (II)
6 design freedom (I)
7 efficiency of combinations (I)

The Component Approach depicted by the Cellophane House is a very promising example of customizable approach which scores highly considering previously set requirements. It allows for high reconfigurability, customizability and invites the user to influence the design and change it. The predefined elements from which the building unit can be assembled are limiting the design though, what makes this case study not perfect.

final score **3.07**/4

5. Participatory design

1 reconfiguration potential (III)
2 modular friendly (III)
3 open source (II)
4 user influence (II)
5 depth of customization (II)
6 design freedom (I)
7 efficiency of combinations (I)

The biggest issue of this approach is the workload which this method requires - each iteration of the design has to presentable and realisable. It is providing a housing system, which is not reconfigurable and poorly modular. Also the depth of customization is low as well as design freedom.

final score **0.92**/4

7. ABC system

1 reconfiguration potential (III)
2 modular friendly (III)
3 open source (II)
4 user influence (II)
5 depth of customization (II)
6 design freedom (I)
7 efficiency of combinations (I)

This customization system is promising and effective but mostly for housing and fixed solutions. It does not offer reconfiguration possibility but is highly effective as a customization tool, and with a parametric software could be implemented in to any building succesfully. Even though it offers limited customization depth and design freedom it succeeds to tame all the possible combinations and not overwhelm the designer and client.

final score **2.21**/4

6. Customer driver approach / IKEA Algot container system

1 reconfiguration potential (III)
2 modular friendly (III)
3 open source (II)
4 user influence (II)
5 depth of customization (II)
6 design freedom (I)
7 efficiency of combinations (I)

This system scores very high in nearly all requirement grades. It is easy both for the client and designer, who in the case of this research are exchanging their duties. Because of this, easiness of reconfiguration and full customization which this system provides allows for effectiveness with low effort. In Algot system this method fills the gap between mass customization which comes directly from the client and mass production. In case of this research, the modules can be customized even deeper as he system is open source, therefore the whole body has endless iterations, but are performed and controlled bottom up.

final score **3.35**/4

Theory of customization

General production patterns are shifting into more and more personalized methods. Even though all of the world economy is founded on oil a lot of industries is looking for alternatives and sustainable solutions. The global market cannot bare any inefficiencies any longer, especially: reduced budgets and economical crises, high demand for quality and a always rising expectation of performance of designs, unoptimized production and construction processes and unefficient technical systems. Because of this, serial production is in retreat and yields upon newer, flexible systems. The economy switches from being dependand on mass production and serial to more personal, scattered and smart.
In architecture the need for custom began being adressed in the 60s. Serial produced housing which answered needs of demographic booms triggered by the end of Second World War changed cities beyond any recognition and resulted in bad districts and urban planning. Today with technology allowing for mass controlling of of multiple projects and products as well as numerically controlled machines connected in virtual networks mass personalized and simultaneously answering combined needs is possible.

This part of this paper showed multiple approaches to the theory of customization. Considering the research question and subquestions about customization, there will be an indication which system or approach helps to meet requirements established in the previous chapter and allows to work on customizability of the following building system.

From the first part of classification, made by Pine II, the only system that is relevant for architecture is **collaborative customization**, which sets a bridge of communication between the designer and the client, which is crucial in this industry. This approach is completely different from the rest mentioned and because of the nature of architectural industry in becomes obvious that only this approach meets the requirements.
Even though a lot of domains of architecture remains with using standardization and assuming that all people (or people that will live in a certain place) have the same needs it can be said that transparent and cosmetic customizations are also applicable but not perfect and do not follow the technological possibilities that are available today.

Customization methods taken from Lampel and Mintzberg provide more to consider. Last three approaches here are applicable to bulding industry and show potential in different scales and building sections - **Customized Standardization, Tailored Customization and Pure Customization**. According to conclusions of Niemeijer (2011) the most suitable method for architecture is Customized Standardization since since it follows the current practice makes buildings from standardized ingredients. However this views seems to be incomplete and imposing a serious progress lag. Thanks to the explosion of technological progress and accessibility of tools these methods single or combined are available and are completely tamable even though gthey require more initial investment, both in terms of finance and intellectual work.

As this paper researches possibilities fostering customizability and reconfigurability of digitally fabricated systems therefore a solution lies somewhere between the mentioned three methods.

Requirements which were obtained in the chapter 1 of this thesis state also that a modular approach shows great potential for designing customized and reconfigurable systems for workspaces. Therfore modularity explained by Duray et al. (2000) is a relevant approach, especially as **component shared modularity and section modularity.**

Component shared modularity shows a tremendous potential in collaborative workspaces, when several users with unique needs can still exchange modules of their workshops and reconfigure their workplaces, using the stock of shared units instead of producing new. Thanks to this method, not only the workspace is being customized and adapted to singular needs but also enhances the collaboration and cooperation between users of the common space. It can be named as ***collaborative customization*** - a strategy in which customization is based on singular needs of users but also affects the whole body in which they all collaborate. That is possible because of constantly changing needs of users, however these needs often match therefore certain modules that will cover those needs can be shared.
Another type of modularity that will be taken into account in this thesis is section modularity. Given the nature of this method is obvious for any structure that is supposed to be customizable. However in the case of a reconfigurable and a temporary system, the additional aspect here is to provide a set of elements that are unified and modular in order to provide changes in the structure immediately. This method allows for such solution.

As for the clients involvement in the design process only the **Core Customization** is taken into consideration. Alford et al. explains this method on an example of automotive industry case - the Land Rover company, which specializes in manufacturing quite narrow field of cars - classic all terrain vehicles - offers special customization options for clients as well as consultations and advise for choosing the right design configurations. The fact that the clients need a very specialized and often unique car is the reason for this heavy involvment of the client into the design. Architecture in general is also a specific case as each design should be unique therefore this level of involvement is unavoidable. Considering workspaces, and especially the fluency and need for flexibility of creative workspaces, the need for clients involvement is even higher.

Design systems

Previously investigated design systems can be divided into 3 basic types:

- those using standardized components in order to arrive with a customized building but are still limited in depth of influence (Sears, FlatPak, Participatory Design).

According to the previous theoretical research on customization this type of design can be marketed as customizable and can be assigned to the *collaborative customization* division (Pine II, 1993).
As for the influence of the client into the production process, this group of customization methods takes place in the *customized standardization* (Lampel and Mintzberg, 1996). Clients influence into the design process can be qualified as *core customization* (Alford et al. 2000).
Modularity in this case qualifies as *cut-to-fit modularity* (Duray et al., 2000).

- those using standardized components in order to deliver a building in which the whole setup is customizable and under significant influence of the client (Component Approach, Customer Driven Approach).

As all architectural objects, this approach can be marketed as a method from the pool called *collaborative customization.* (Pine II, 1993)
As for the involvement in the production phase, this group applies to *tailored customization* (Lampel and Mintzberg, 1996) and in design for *core customization* (Alford et al., 2000).
Modularity in this case qualifies as *section modularity* (Duray et al., 2000).

- and those which provide multiple solutions thanks to algorythimic or parametric control over the design. The result is not coming from the elements but from the requirements and spatial needs from the client, to which the elements or structure can be adapted (Shape Grammars, ABC System).

This approach can be marketed as *collaborative customization.* (Pine II, 1993)
In this case the involvement of the client into the production phase is strongest therefore is classified as *pure customization* (Lampel and Mintzberg, 1996). Clients influence can be summarized as *core customization* (Alford et al. 2000).
These systems do not present any modularity.

From these, the highest scores are obtained by the second group. They use elements that are created accordingly to the needs of the target receiver - the customer - what permits a high level of customization. But thanks to the method presented by Customer Driven Approach (and mostly IKEA Algot system) tailoring to the clients needs is performed in two levels. First, the components are made accordingly to customers expectations and needs, based on research and analysis. Then, on the second level, thanks to the self-assemble and self-arrange system, the customization takes part again - it is them who arrange the whole body as they like. On a scale of a IKEA closet that means the client can arrange themself where exactly they will place baskets, racks and hangers. On a building scale, the user can decide where will he have the door, the window, a wall or a staircase. Therefore, the clients assemble the structure themselves not only how they want to, but also from elements that are tailored to their needs.

While the last group has a huge potential as it allows for control multiple solutions at once and provide endless configurations it does not exactly apply to consideration of this research. It shows tremendous possibilities for architecture branches like dwellings, where each housing unit is unique, and does not change through time. However, in cases when the needs are similar, but vary in the spectrum of some domain, and change through time, this sort of customization method gives away to those like Customer Driven Approach.

Fig. 1 - IKEA Algot system (www.ikea.com, 2016)

2.08 Final method of customization

The resulting method should be aiming to meet the following conditions:

- be classified as an example of collaborative customization (Pine II, 1993);

- provide clients involvement on the level of tailored customization or pure customization in terms of production (Lampel and Mintzberg, 1996) and core customization as for the design (Alford et al. 2000);

- in terms of modularity it should be classified as an example of component shared modularity and section modularity (Duray et al., 2000);

- combine different approaches, standardization and customization on different levels to achieve a clear and effective mass customization method which will allow for flexibility and personalization of the final design.

Final method of customization scoring

1 reconfiguration potential (III)

2 modular friendly (III)

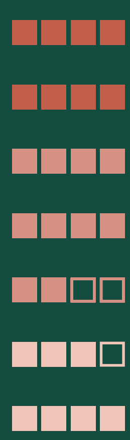
3 open source (II)

4 user influence (II)

5 depth of customization (II)

6 design freedom (I)

7 efficiency of combinations (I)



final score 3.64/4

According to the previously formed conclusions the mass customization system will follow the method explained by the diagram:

Fig. 2 - customization method (own illustration

1. “bricks”

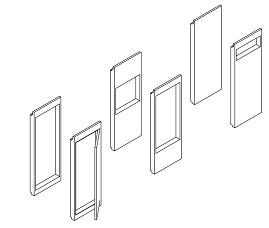
Modules of the workspace such as:
- furniture
- walls and partitions
- staircases
- storage modules.
- primary structure modules

etc.

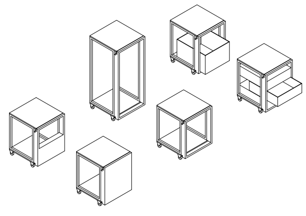
customization pattern:

Standardized elements pre-customized accordingly to research on needs. Open source and designed in modular way for endless reconfigurations.

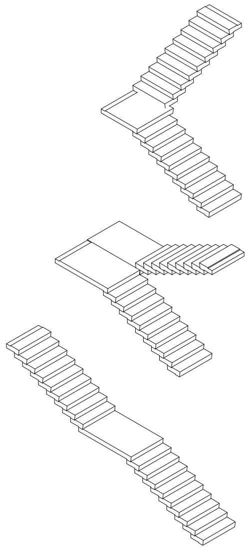
1. “bricks”



1a. wall modules



1b. furniture modules



1c. staircase mod.

2. “units”

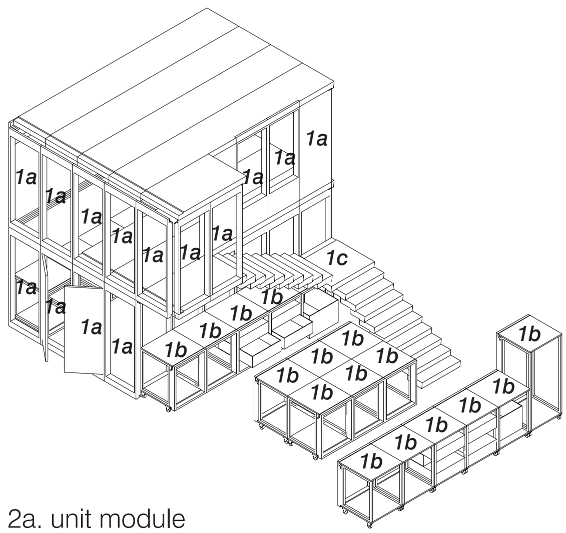
Workspaces - combinations of “bricks” into rooms and spaces.
Levels of privacy thanks to different spaces available:
- private workshop
- design studio
- storage space
- semi-private space

etc.

customization pattern:

Fully customized by users themselves who assemble and reconfigure their spaces.

2. “units”



2a. unit module

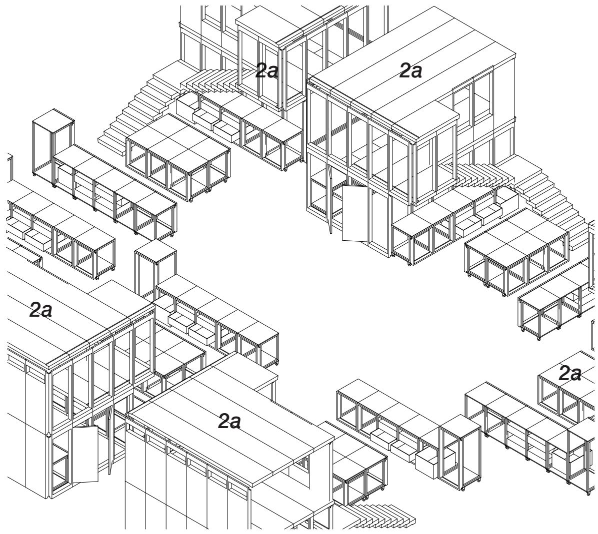
3. “interior”

Combinations of “units” - customized and reconfigurable spaces shared among many users.

customization pattern:

Collaborative customization - customization is based on singular needs of users but also affects the whole body in which they all collaborate.

3. “interior”



3a. interior

4. “exterior”

Stardardized but reconfiruable outer shell using custom, locally made structure and stock outer elements, available on market. Combines all previous elements and standard finish products.

3.00

digital fabrication

"An architect must be a craftsman. Of course any tools will do; these days, the tools might include a computer, an experimental model, and mathematics. However, it is still craftsmanship – the work of someone who does not separate the work of the mind from the work of the hand. It involves a circular process that takes you from the idea to a drawing, from a drawing to a construction, and from construction back to an idea"

– Renzo Piano
(Buchanan, 2003)

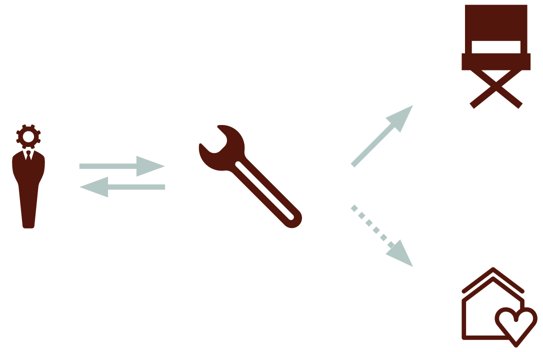
Digital fabrication is a relatively new and still avantgarde tool in todays building industry and architecture world. That is mostly because it is not yet so reliable and proven to work in large scale developments and rarely leaves academic insitutions to be used commercially (Remmerswaal, 2015). Therfore a question about relevance of this technical approach might be posed: is digital fabrication really needed in this case? Since digital fabrication allows for non standard and custom solutions the main reason to use it is usually that:

Digital Fabrication means added quality.

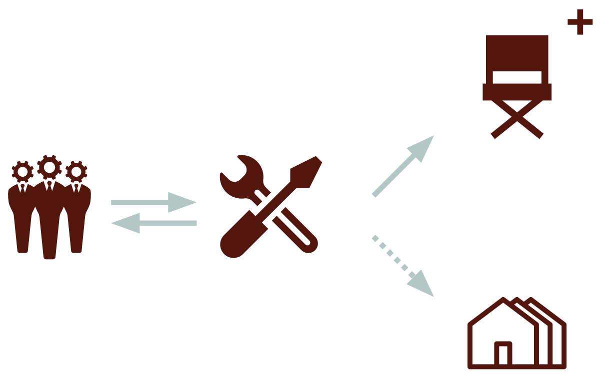
What is the quality in case of this project? Customizablity, reconfigurability and open source building system, which can be influenced by their users. Apart from that:

This research aims to provide a solution to house crafstmen and provide workspaces for them. Many of them already use digital fabrication tools for making their products or items for personal use.

If the client already has the tools, knowlegde and some experience why would they not build their own workplaces and housing? Thanks to that they can always influence the design and reconfigure the building.



Thanks to the fact of being united as a collaboration it is possible to produce something bigger that only a building system. Opportunity of improving their own products, collaborating and working on joint projects becomes possible. A unique, creative community emerges and infuences the neighbourhood.



Digital fabrication is an extremely broad topic and is evolving rapidly. There were many studies on digital manufacturing, division, classifications etc, therefore author of this paper will not proceed with elaborating on that. Even though the number of publications is massive many of the relatively new books and research papers are becoming quickly outdated, thanks to new techniques popping out. It is not the technology that changes in particular - that applies to short span of time, considering a few years - but ways of utilizing certain material and machining combinations and geometrical approaches. For example, a CNC milling mashine is a tool which is known since the 70s; however using it with parametric design tools in order to materialize data driven design of a foldable origami canopy is a rather recent invention. It is the methods of producing those canopies and architectures that evolves quickly, not only the machines. Therefore the aim of this part of the research is to find the best method or to figure out a new, hybrid combination of presented ones.

However while studying particular books the reader might still get an impression that these techniques are so fresh that their application in architecture is limited to interiors, decorative elements of demonstrational pavilions or canopies. Most of them are not ready yet to be implemented in building industry. An example of that can be noticed in Digital Fabrications (Iwamoto, 2009) or Material Strategies (Beorkrem, 2013). Even though a fascinating literature and extremely inspiring, examples from these books cannot be used for building industry, therefore evaluation of these considering previously formulated requirements would not bring any profit.

Digital Processes (Hauschild, Karzel & Hellstern, 2011) however, presents more utilitarian approach to digital fabrication. Thanks to this book and other parallel studies significant fabrication methods and material combinations that are relevant for this study can be distinguished and further evaluated considering previously concluded requirements. Investigated methods are chosen from many - a lot of theoretically applicable were rejected because of initial, obvious drawbacks - as for example robotically aided assembly from many elements.

The initial selection of material/technology combination was based on assessment of the feasibility of utilizing such approach in a creative community. It had to be produced by digital fabrication machines and be modular and easy in assemble in some way. Also, most of the techniques had some time for maturing and be tested in multiple ways, or even be introduced to the building market.

The methods which will be evaluated and checked are as following:	**material**	**tools**
1 **precast concrete elements from foam moulds fabricated using cnc milling (Beorkrem, 2013) and (Hauschild, Karzel & Hellstern, 2011);**	**concrete**	**CNC mill (specialized)**
2 **Cast Formwork System (Remmerswaal, 2015);**	**concrete**	**CNC mill**
3 **D-Shape large scale concrete printing (Hauschild, Karzel & Hellstern, 2011), (Lim et al., 2011);**	**concrete**	**3D printer**
4 **An Open-Source Building System with Digitally Fabricated Components (Stoutjesdijk, 2013);**	**wood**	**CNC mill**
5 **Robotically woven carbon fiber structures (Menges, 2015);**	**carbon and glass fibers**	**robotic arm**
6 **Cradle Molding Device (Griffith et al., 2012);**	**clay**	**CNC mill**
7 **An open source digitally fabricated system using fiberglass - a hybrid envisioned by the author.**	**fiberglass**	**CNC mill**

To prove that the best material + digital manufacturing combination is relevant it will be confronted and compared with traditional approaches (Appendix 9, p. 179):

8 steel frame structures;	**steel**	various
9 concrete beam - column systems.	**concrete**	various

Other similar technologies categorized as concrete 3D printing were also taken into account like Contour Crafting (Khoshnevis et al., 2001) or Concrete Printing (Lim et al., 2009) but were not investigated because tese are not using common digital fabrication machines. Also, Mesh Moulds (Gramazio and Kohler et al., 2014) were taken into account, however this technology is not mature enough to be used in building industry and it allows for complex, non standard shapes, which are not needed in the case of this research.

3.03 requirements for digital fabrication

In the following part of this chapter, the aforementioned methodologies will be evaluated upon previously formed requirements. Before that will be done, relevance of certain requirements will be elaborated. All the requirements have their weights calculated in the Appendix 5, p. 161:

Technology:

1 reconfiguration potential (III)
the chosen technology have to provide possibility of easy reconfigurability of the strucure and setting, so that the users will be able to change their work-places at any time they want;

2 modular friendly (III)
chosen method has to allow for modular structure which will help with reconfiguration;

3 customizable friendly (III)
chosen method has to perform well along with the mass customization method previously defined;

4 ability to perform as an integral part of the building (III)
elements produced by the chosen technology must be compatible with other (standard) elements or sub-structures of the building. For example, a primary structure produced with the chosen technology must allow for attaching the secondary technology or installations;

5 easy assemble (II)
the chosen technology must allow for easy assembly by users themselves, without significant or irreplacable help of specialized workers from outside;

6 easy dissasemble (II)
as mentioned before, but also - the chosen technology easy disassembly will enable for easy interventions in the buildings setup, enhancing reconfigu-rability and customizability;

7 strcuture durability (II)
the structure has to hold singificant loads

8 rooflights possible (I)
technology chosen must allow for rooflighting as it is most desirable for clients as well as daylight.

Material:

9 large span durability (III)
the material properties have to be meeting large spans (at least 8m*);
**this value seems not a large span in a general understanding in todays engineering, but it still is quite challeng-ing for digital fabrication systems which usualty use raw materials*

10 multifloor durabiliy (III)
the chosen material has to be strong enought to bear and transfer loads in a multifloor structure (up to 4 floors);

11 material weight (III)
the chosen material cannot be too heavy; elements produced should be easy to carry by one person;

12 toxicity (III)
the material cannot be toxic. Also it cannot release any toxic byproducts while machining;

13 recyclable (III)
the material has to be recyclable;

14 reusable (II)
material has to be durable enought so that fabricated elements can be rear-ranged and recombined without need of producing new.

15 additional physical characteris-tics(II)
some materials provide additional parameters that enhance the building performance, like heat resistance, etc.;

16 environmental impact (II)
the material cannot have a negative environmental impact

17 material price (I)
the cheaper the material the better. However, because the building is a owned and funded by many entrepre-neurs, therefore the low weight of this requirement.

Process:

18 produced by common digital fabrication machines (III)
for example: machines like plasma cutters, even though they count as digitally controlled, are not common between makers etc.;

19 elements size (III)
elements cannot be too big so that a person will not handle it easily;

20 easy to produce (II)
some techniques require supporting actions which complicate the process;

21 material waste (II)
the less the better;

22 cognitive ergonomics (II)
a technology must present logical con-nections between building elements;

23 machine price (I)
the machine cannot be too expensive;

24 process time (I)
longer production processes are worse;

25 assembly time (I)
longer assembly time disables cus-tomizability and reconfigurability ease;

26 amount of elements (I)
big amounts of elements are confus-ing;

27 elements variation (I)
less varied elements are easier to grasp;

28 additional tools needed (I)
use of additional tools complicates the assembly and production and pro-longs the process;

29 additional components needed (I)
as mentioned in the point before, addi-tionaly, extra components rise the cost.

30 additional efforts (I)
additional actions in order to finish the building process cost extra money and time

31 additional assembly costs (I)

1
Precast concrete elements from moulds fabricated using cnc moulding

(Beorkrem, 2013), (Hauschild, Karzel & Hellstern, 2011)

product material	concrete
supporting material	steel composites
finishing needed?	raw is sufficient
optional finishing	glazing polishing painting
max. el. size [mm]	15500 3000 500 dep. on machine
geometry options	2D
geom. file input	.dxf .dwg
precision of the machine	± 5 mm
t constr: height mm/m^2	10 s
common application	Construction industry
manufacturing comp.	Vollert Anlagenbau GmbH

Need for custom precast elements is high in building industry. Usually those are made by manual effort thus CNC machine is a good application of precision and custom form in this situation. Thanks to the methods used by Vollert Anlagenbau the process is carried out by a numerically controlled moulding robot.

Compared to the traditional manual method of precasting Vollert is able to produce elements up to 4 times faster. 50 pallets with elements can be manufacutred in one working day of 8 hours, which means an equivalent of 110 walls approximately. Machine and nature of this method provide limitations - this is a 2D process. The size of elements is limited by the transportation - the bed of a trailer truck which has dimeniosns of 12 x 3 m. Thickness of the element goes up to 0.5 m.
Thanks to the process any kind of wall setup can be produced with use of parametric design methods. Here the idea of mass customization gets materialized into solid building element as any variation can be applied without changing costs and additional effort.

Moreover, this method allows for integration of additional features into produced elements. If a series of walls are produced it is possible to add insulation layers or technical appliances inside the element during the production. That enhances the speed and integrity of the whole construction. That reduces costs of the whole building investment.
Future development predicts adding more dimensions to the process - allowing for production of curved elements and more customization in form. Also, it is planned to broaden the variety of build - in features to interior layers or fixed window modules.

fabrication process

stage 1 mould elements are placed on the cnc machine bed by the machine head.

stage 2 moulds are locked with magnets

stage 3 machine head inserts reinforcement and pours concrete inside the predefined areas

stage 4 concrete dries and elements are taken to the construction site

stage 5 building is erected using precast elements

1 reconfiguration potential (III)	■■□□
2 modular friendly (III)	■■■□
3 customizable friendly (III)	■■■□
4 ability to perform as an integral part of the building (III)	■■■■
5 easy assemble (II)	■■□□
6 easy dissasemble (II)	■□□□
7 structure durability (II)	■■■■
8 rooflights possible (I)	■■■■
9 large span durability (III)	■■■■
10 multifloor durabiliy (III)	■■■■
11 material weight (III)	□□□□
12 toxicity (III)	■■□□
13 recyclable (III)	■■□□
14 reusable (II)	■□□□
15 additional physical characteristics (II)	■■■□
16 environmental impact (II)	■□□□
17 material price (I)	■■■□
18 produced by common digital fabrication machines (III)	□□□□
19 elements size (III)	■□□□
20 easy to produce (II)	■■□□
21 material waste (II)	■■■■
22 cognitive ergonomics (II)	■■■■
23 machine price (I)	■□□□
24 process time (I)	■■■□
25 assembly time (I)	■■■■
26 amount of elements (I)	■■■■
27 elements variation (I)	■■■■
28 additional tools needed (I)	■□□□
29 additional components needed (I)	■■■■
30 additional efforts (I)	■■■□
31 additional assembly costs (I)	■■■■

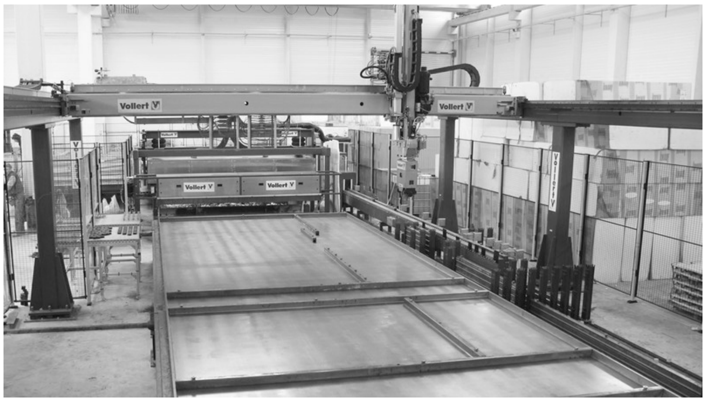


Fig. 1 - cast elements are laid on the cnc bed (www.vollert.de, 2016)

Fig. 2 - cnc bed (www.vollert.de, 2016)

Scoring comments

This method presents promising perspectives for building industry in general. It is highly efficient and would certainly be a good option for mass customized housing etc, as it proves to be relevant for mass customization and performs perfectly as an integral part of the building.
However in this case it does not suit certain most important requirements.
Reconfiguration potential is quite low - as the elements as concrete walls are heavy, it is impossible to replace or move them without a crane. That also influences dissasembly ease, which is low.
When is comes to the material - elements made of reinforced concrete are bulky and heavy - it is impossible to assemble any structure without any additional devices.
Moreover, concrete needs cement as a chemical binding component - which emits a lot of CO_2 into the atmosphere.
What is more - this method needs a specific machine that is not used by any of craftsmen - it is designed spefically to produce only these building elements. It is useless in a workshop. However, a similar method, using tools used in a common workshop can be developed and suit the needs of this research.
Finally, the price of the machine and additional tools and effort to erect a structure with this method compose the relatively low score.

2.48/4 final score

2
Precast concrete slabs from foam moulds fabricated using CNC - Beyond the Slab II

(Block et al., 2014)

product material	concrete
sup-porting material	extruded foam materials, wood
finishing needed?	raw is sufficient
optional finishing	glazing polishing painting
max. el. size [mm]	2750 1000
geom-etry options	3D
geom. file input	.stl .iges
precision of the machine	μ region
material compo-nents	- cement - microsilica - aggregate - water - placticizer - steel fibres 12mm
common applica-tion	Construction industry
manu-facturing comp.	Streamline Automation

Beyond the Slab II is another precast system, this time for slab components. However Beyond the Slab II is could be utilized rather as a part of building than a holistic system, this system developed at ETH Zurich presents a high potential of use.

The slab system operates on a size of ratio 1/2.75 and allows for production of extremely thin floors. The slab has voids carved out with 1cm ribs left which provide enought strenght of the structure to bear loads. Thanks to computational form finding researchers were able to optimize the layout of the ribs and shape of the vault. The result was aimed to be a compression - only shell under its own weight and dead load, combined with an optimized arrangement of ribs for the remaining live loads combinations what allowed to take out the traditional rebar cages necessity compeletely. The design was optimized using parametric design tools. Optimization and simulation part was followed by real life experimentation with the fabricated element. Further research will improve the predictions about the material - properties from simulation and real life testing do not match as because of impossibility of using a vibrator for the concrete it is not possible to define actual parameters.

Even though this method is under development and has not been proven to work in the building industry, it is worth considering as a component of a digitally fabricated building. It can provide horizontal elements of a building in combination of other technologies for the vertical parts.

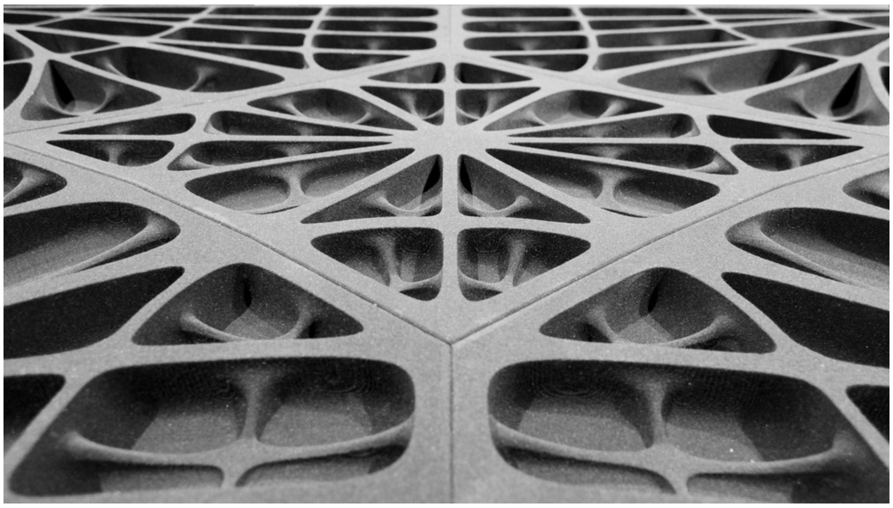


Fig. 3 - rich in ribs top surface of the Beyond the Slab II (Block, 2014)

fabrication process

stage 1 — foam moulds cut on a wire cutting CNC machine for the top part

stage 2 — bottom part moulds from wood are cut with a CNC router machine

stage 3 — latex based coating added to the moulds for easy disassembly

stage 4 — concrete poured in

stage 5 — moulds disassemblied

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durabiliy (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteristics (II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

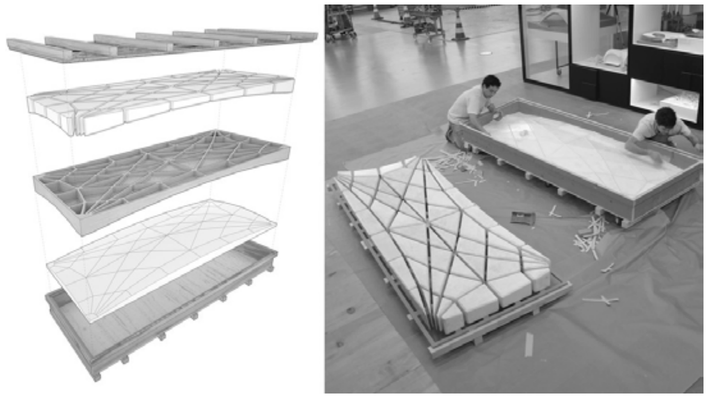


Fig. 4 - cast elements are laid on the cnc bed (www.vollert.de, 2016)

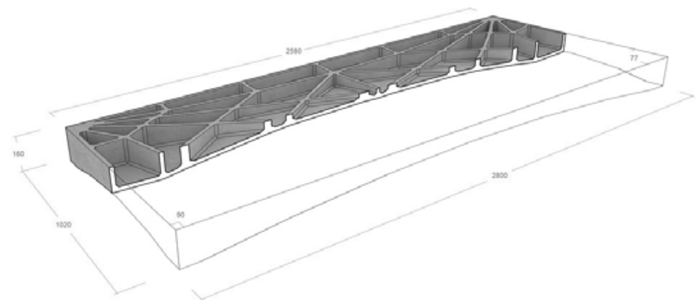


Fig. 5 - cnc bed (www.vollert.de, 2016)

Scoring comments

Beyond the slab II is definately an advance in concrete slab systems. The fact that it does not need traditional reinforcement and combines algorythmic optimization makes it a fully working package which will hopefully improve building industry soon. However it is still under development and present a lot od drawbacks.
However some negative aspects are present, considering purpose of this research. This system does not present much field for customization, the form of the slab probably cannot be perforated, only the dimensions can be affected but also with limits.
Potential for reconfiguration is limited because of the weight and size of the slab. The fact that it is a one single element, a big concrete plate makes it obviously impossible to ba handled without tools like crane etc.
Weight of the structure and size of it is another unacceptable issue, along with no possibilities for reuse or recycle. The latter are limited thanks to use of steel fiber reinforcement - this makes the crumbled concrete agent difficult to reuse. Also, concrete as a material is not very environmental friendly, what was mentioned in cases before. Moreover, this particular mixture is expensive, however this can pay off because of the speed of production and lack of traditional reinforcement cages.

2.50/4 final score

3
Cast Formwork System

(Remmerswaal, 2015)

product material	concrete
sup-porting material	wood (betonplex)
finishing needed?	raw is sufficient
optional finishing	glazing polishing painting
max. el. size [mm]	4500 4500 2500
geom-etry options	2D
geom. file input	.dxf .dwg
precision of the machine	0.2-0.5 mm
material compo-nents	concrete: rebar reinforcement cages
common applica-tion	Construction industry
manu-facturing comp.	CAST Formwork System

CAST is a easy assembly formwork system using plywood (betonplex) for multifloor concrete housing strutures. This project was initiated by Nadia Remmerswaal in the 2015 at TU Delft as her master graduation project for Indonesian housing in Bandung. After being a succesfull academic project, Remmerswaal is now working on implementing her design in real life and operates as a company, collaborating with Indonesian authorities.

The point of this system is not intenting an easy assembly building method, but rather improving the one that is already well set in the culture of constructing in Bandung. The problem of this place is that people there are already using concrete casting, however their methods and technology are very inacurate and because of that the structures erected are dangerous.

Assembly time of a single module (Fig. 5) is about 5 days, considering 4-5 people working on it, 8 hours per day. Milling time of all elements took about 18 hours. However, if a longer working day is considered, and inefficiencies of assembly like moving and sorting the elements would be eliminated, this process could be finished in 2-3 days.

Key requirements for this building system were durability, multi storey availability, low material costs, machinery low costs, low level of assembly difficulty, personalization and use of local materials. As some crucial requirements align with purpose of this research, this method presents potential for implementing.

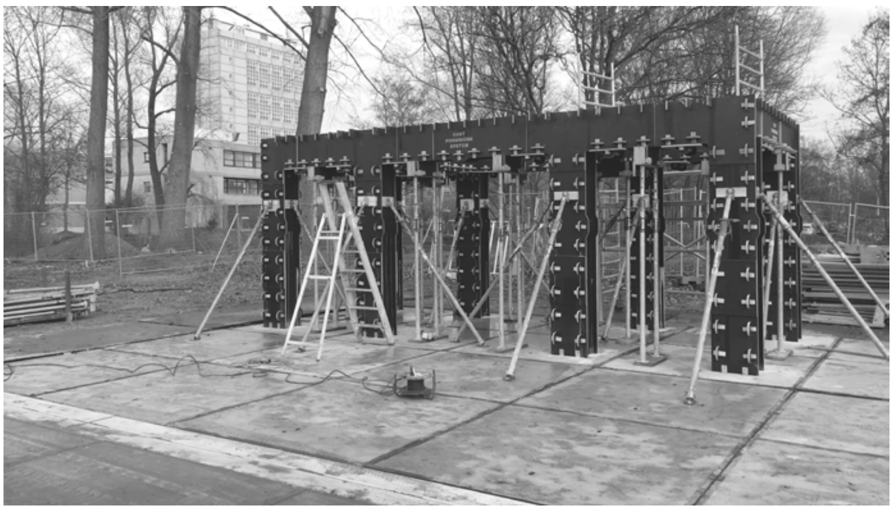


Fig. 6 - ready formwork module waiting for concrete pouring (own photo)

fabrication process

stage 1 → cast elements are milled with a CNC machine.

stage 2 → cast elemets are transported to the site

stage 3 → formwork is assembled, tightened with steel supports and fixed to the ground

stage 4 → rebar reinforcement cages are installed

stage 5 → concrete is poured in and vibrated

stage 6 after drying the formwork is disassebled and ready to be reused

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durabiliy (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteris-tics (II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

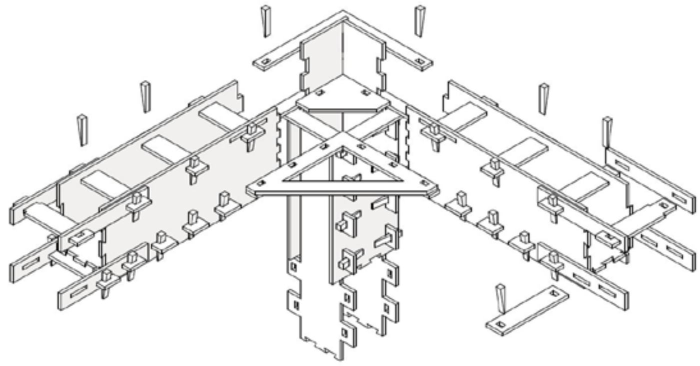


Fig. 7 - assembly of a structure's corner (Remmerswaal, 2015)

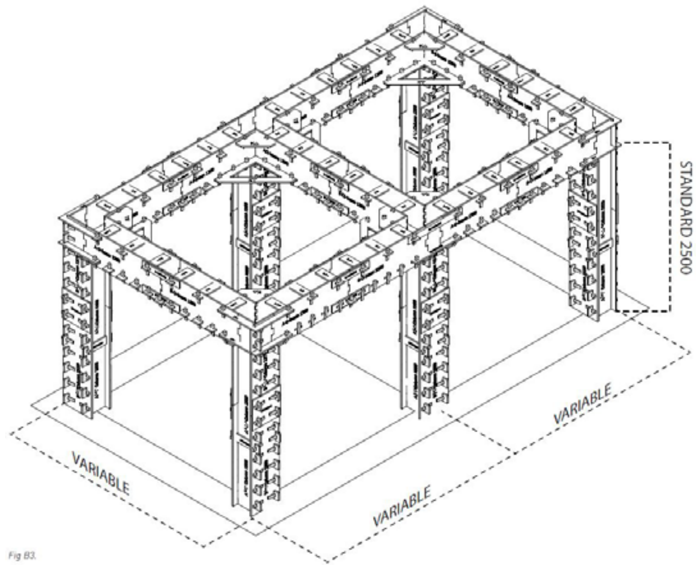


Fig. 8 - formwork module (Remmerswaal, 2015)

Scoring comments

CAST formwork system is a very promising and easy assemly system. However, it is designed for different con-ditions and purposes, therefore a lot of requirements of this research are not met.
This system is designed to perform as a permanent housing structure therefore the reconfiguration potential is poor. The structure can be customized before building as the method is an open source one, but after solidifying it is impossible to change it. Therfore, also the disassembly is impossible without specialized tools.
As it was designed for housing, not for production, CAST also has certain limits in span values. On one hand, beause of limitations of the formwork spans, on another - limits of square section concrete beams.
Usual issues with conrete occur as well, mentioned in cases before.
Author of this research had a chance to volunteer in the assembly of CAST prototype in TU Delft in December 2016. Thanks to that it was possible to understand the ease of this process and on the other hand - additional actions needed which complicate the process, like support for the formwork beams, and a requirement of stable ground, which might be maybe included in the system, in further development.

2.66/4 final score

4
D-Shape large scale concrete printing

(Hauschild, Karzel & Hellstern, 2011), (Lim et al., 2011), (Dini et al., 2013)

product material	artificial sandstone
supporting material	inorganic seawater binder, magnesium based binder
finishing needed?	raw is sufficient
optional finishing	plastering grinding insulating polishing
max. el. size [mm]	6000 3000 3000
geometry options	3D
geom. file input	.stl .iges .step
precision of the machine	20 mm
material components	- cement - microsilica - aggregate - water - placticizer - steel fibres 12mm
common application	Construction industry, large scale protytyping
manufacturing comp.	Monolite UK

The D-Shape technology utilizes a artificial sandstone powder distribution process, which is selectively solidified using two types of binders. Each layer of build material is laid to the preferred thickness and compacted. After that nozzles mounted on a gantry frame distribute the binder where the part is to be solid. Once a part is complete it is then dug and cleansed from the the loose powder. The process has been used to create 1.6 m high architectural experiments called “Radiolaria” - fig. 11.

In fact, this process is big scale 3D printing, therefore it shares both common advantages and disavdantages of this technique. Thickness of the layer is around 13 mm, which, compared to general spatial printing might suggest that this is a quick process. This however is incorrect, as the scale is much bigger. What is another derivative from this fact is the roughness of the resulted surface. Therefore, to achieve aestethical effects, additional processing is needed.

What is positive and promising about this technology are good mechanical properties and high compressive strenght value, which allows for multi-floor, big scale structures.

Fig. 9 - concrete element is being printed (www.architectsjournal.co.uk, 2016)

fabrication process

stage 1
artifical sandstone powder is distributed

stage 2
binding liquids are distributed where needed

stage 3
material solidifies and structure is cleaned from loose powder

stage 4
complete elements is transported on site

1 reconfiguration potential (III)	■□□□
2 modular friendly (III)	■■□□
3 customizable friendly (III)	■■■■
4 ability to perform as an integral part of the building (III)	■■■□
5 easy assemble (II)	□□□□
6 easy dissasemble (II)	□□□□
7 structure durability (II)	■■■■
8 rooflights possible (I)	■■■■
9 large span durability (III)	■■□□
10 multifloor durabiliy (III)	■■■■
11 material weight (III)	■□□□
12 toxicity (III)	■■□□
13 recyclable (III)	■■■■
14 reusable (II)	■□□□
15 additional physical characteris-tics(II)	■■■□
16 environmental impact (II)	■□□□
17 material price (I)	■■□□
18 produced by common digital fabrication machines (III)	□□□□
19 elements size (III)	□□□□
20 easy to produce (II)	■■□□
21 material waste (II)	■□□□
22 cognitive ergonomics (II)	■■■■
23 machine price (I)	■■□□
24 process time (I)	■□□□
25 assembly time (I)	■■■□
26 amount of elements (I)	■■■■
27 elements variation (I)	■■■■
28 additional tools needed (I)	■□□□
29 additional components needed (I)	■■□□
30 additional efforts (I)	■□□□
31 additional assembly costs (I)	■■□□

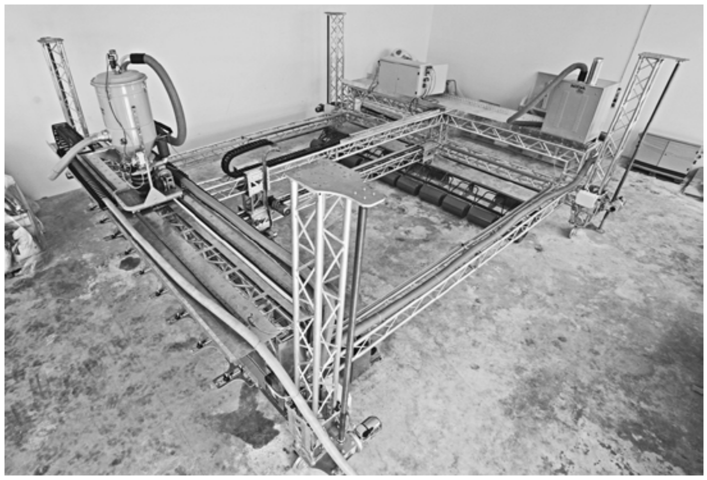


Fig. 10 - D-Shape 3D printer (www.d-shape.com, 2016)

Fig. 11 - Radiolaria experimental structures, view from inside (www.hiro-studio.com, 2016)

Scoring comments

D-Shape system is a highly promising technique, although, as Dini et al. indicates it is rather usable as a lunar building method, than for example asset for this research. Various factors define the low score.
Main reasons for this is low potential for reconfiguration and modularity, as a concrete part is of low surface quality and precision, theorefore it is hard for it to cooperate with other parts of a building. Another issue is handyness - the pieces are huge and very heavy - it is impossible to assemble it without use of specialized equipment. Also, the printer is a device specially made for production of the concrete elements. It is not a common digital fabrication tool, perhaps it could be used by makers but it is not universal while the material purpose is mostly construction.
Another downside is the time of the process.
Along with heavy loads resistance a posivite aspect is customization friendlyness, as the printer can produce any kind of geomentry, tailor made.

final score

2.05/4

5 Open-Source Building System with Digitally Fabricated Components

(Stoustesdijk, 2013)

product material	wood, plywood
sup-porting material	-
finishing needed?	raw is sufficient
optional finishing	painting varnishing
max. el. size [mm]	depends of bed size
geom-etry options	2D 2.5D
geom. file input	.dxf .dwg
precision of the machine	0.1 - 0.2 mm
finishing needed or other efforts	edges sanding varnishing - depends on purpose and material
common applica-tion	furniture industry
manu-facturing comp.	The New Makers

Stoutjesdijks Haiti Shelter is a proposal for rapidly growing population. It using only a CNC milling machine and wooden sheets of 18 mm thickness and allows for easy assembly by unqualified workers using no additional tools. Puzzle-like assembly is intuitive and quick because of 2.5D milled friction wooden locks thanks to which the assembly process requires no tools. The whole kit of parts composing a house can come in a one flat package with a IKEA inspired assembly manual.

There are other examples of use of this approach - WikiHouse or Lawrence Sass's Instant House. These all use the same technology, which makes housing affordable and easy to build for common people. This is a perfect example of democratizing design, as Stoutjesdijk claims that his project is open source and thus customizable.

Another pro is that it uses wood and its derivatives, which makes the whole process easy and cheap and moreover - sustainable. Also, wood is widely used by makers because of the ease of machining and processing.

All this makes this method attractive considering this research.

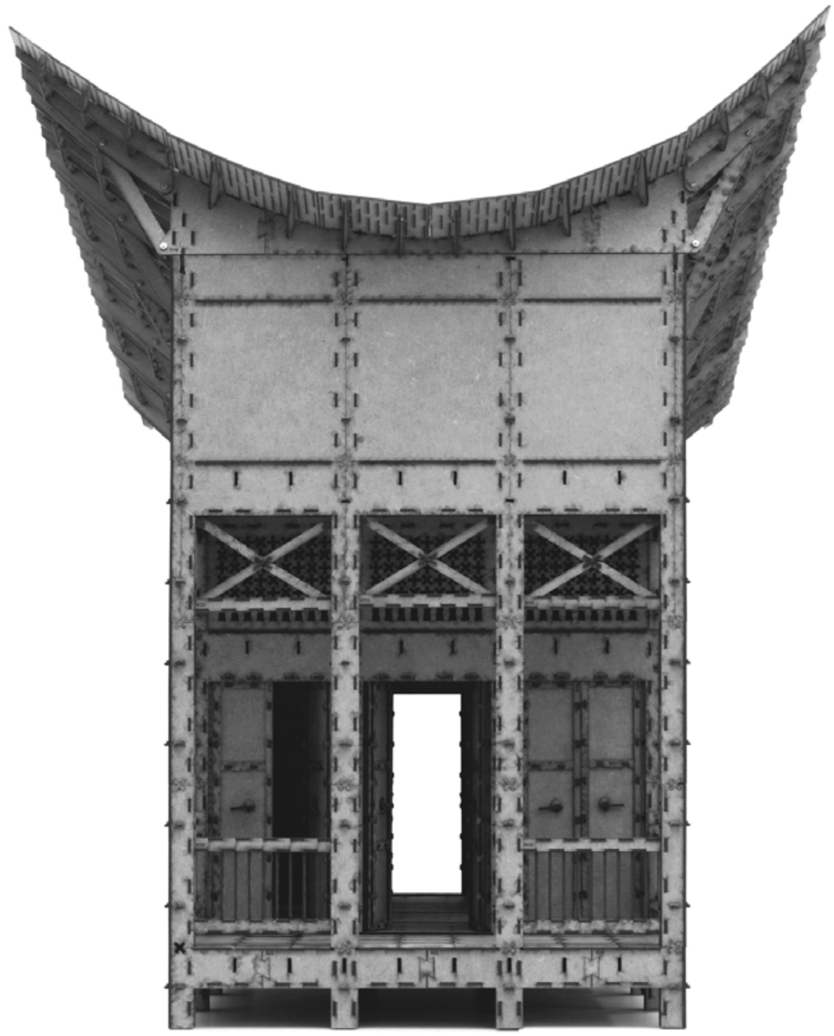


Fig. 12 - Haiti Shelter house (Stoutjesdijk, 2013)

fabrication process

stage 1 — material sheets are placed on the cnc milling machine bed

stage 2 — elements are cut from sheets

stage 3 — elements are transported to the site

stage 4 — structure is assembled from the elements (optional: elements are sanded before assembly)

stage 5 (optional) — structure is varnished etc.

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durability (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteris-tics(II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

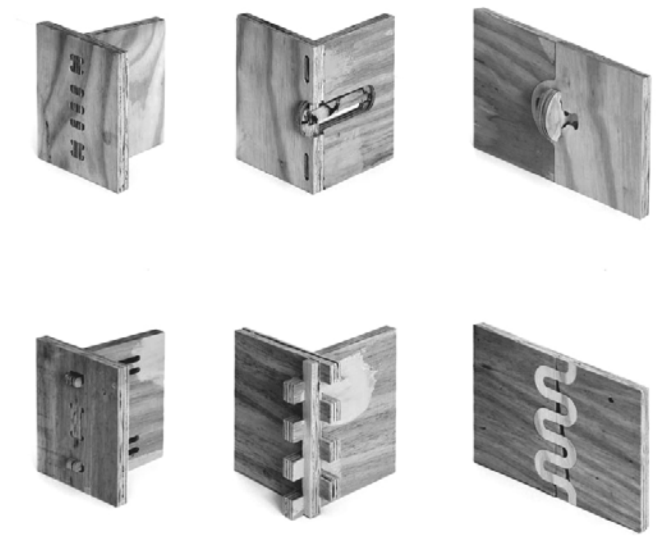


Fig. 13 - various wooden locks CNC milled (Stoutjesdijk, 2013)

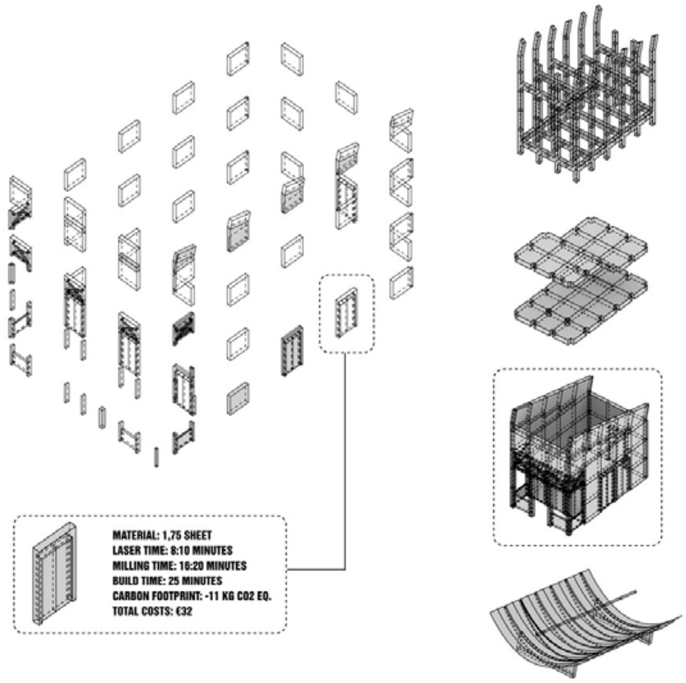


Fig. 14 - building elements (Stoutjesdijk, 2013)

Scoring comments:

Stoutjesdijk's building system presents very high potential of usage considering this research. It is easy to assemble, quick and effective, easy to customize. It shows very high possiblities of reconfugurability while the material is durable enough to be reused but as well recycled. Wood is also light, so it can be easily assembled with no use of additional cranes etc.
However, wood cannot carry heavy loads. It scores low in large span and multifloor durability what limits this method to small scale objects only.

3.11/4 final score

6
Robotically woven fibre structures

(Menges, 2015)

product material	carbon and glass fibers, glass plate
sup-porting material	steel frame
finishing needed?	raw is sufficient
optional finishing	-
max. el. size [mm]	fixed so far, no other data available
geom-etry options	3D
geom. file input	n/a
precision of the machine	± 10 mm
material compo-nents	- carbon fibers - glass fibers - reisin
common applica-tion	Construction industry
manu-facturing comp.	KUKA

Menges et al. investigate fibrous structures in their research. The Elytra Pavillion (fig. 15) is the first modular approach of theirs using fibers technology, therefore it reveals potential in this research.
The fibrous composite structure of the installation only consists of two basic cells - canopy and the column cells. Flat roof composed of canopy cells can be covered with transparent glass roof panels. Both cells are made from the same load-bearing fibres: transparent glass fibres and black carbon fibres. The production process is an innovative robotic winding process developed by the project team, which compared to other composite fabrication methods does not require any mould or procution line, so that reduces waste significantly. Each cell is made by a robotic arm which winds resin-saturated glass and carbon fibres onto a hexagonal winding tool. In this process, the first layer of transparent glass fibres form a spatial scaffold onto which the second layer of black carbon fibres are applied and serve as primary load bearing structure, as they are stiffer and strength than the glass fibres.
Once the fabrication is complete the material hardens and the winding tool can be taken out and reused.
Each canopy cell is adapted to its specific loading condition through a differentiation of its fibre arrangement, density and orientation, resulting in a very material efficient and light structure, weighting 9kg/m².
Thanks to this low weight, this method shows significant potential as it can be reconfigured and customized and on the other hand is possible to be assembled by people without use of big cranes.

Fig. 15 - Elytra pavillion assembly (Victoria and Albert Museum, 2016)

fabrication process

stage 1	stage 2	stage 3	stage 4	stage 5
resin saturated glass fiber is winded onto a hexagonal form	resin saturated carbon fiber is winded on the previously winded glass fiber	modular element dries	hexagonal tool is taken out and the element is transported to the site	structure is assemblied

1 reconfiguration potential (III)	■■■□
2 modular friendly (III)	■■■■
3 customizable friendly (III)	■■■□
4 ability to perform as an integral part of the building (III)	■□□□
5 easy assemble (II)	■■■□
6 easy dissasemble (II)	■■■□
7 structure durability (II)	■■□□
8 rooflights possible (I)	■■■■
9 large span durability (III)	■□□□
10 multifloor durabiliy (III)	■□□□
11 material weight (III)	■■■■
12 toxicity (III)	■□□□
13 recyclable (III)	■■■□
14 reusable (II)	■■□□
15 additional physical characteristics(II)	□□□□
16 environmental impact (II)	■■□□
17 material price (I)	□□□□
18 produced by common digital fabrication machines (III)	■■□□
19 elements size (III)	■■■■
20 easy to produce (II)	■■■□
21 material waste (II)	■■■■
22 cognitive ergonomics (II)	■■■■
23 machine price (I)	□□□□
24 process time (I)	■■□□
25 assembly time (I)	■■■■
26 amount of elements (I)	■■■■
27 elements variation (I)	■■■■
28 additional tools needed (I)	■■■■
29 additional components needed (I)	■■■■
30 additional efforts (I)	■■■■
31 additional assembly costs (I)	■■■■

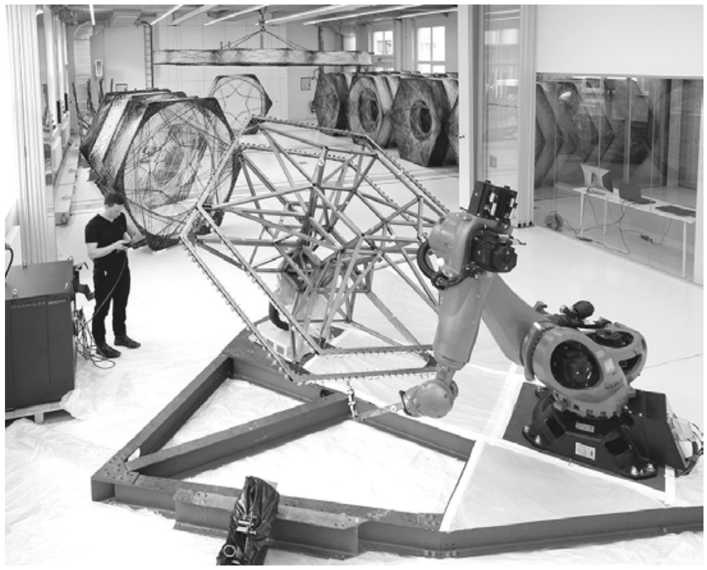


Fig. 16 - hexagonal winding tool in the center and robotic arm before fabrication (Victoria and Albert Museum, 2016)

Fig. 17 - cells are carriable by people (Victoria and Albert Museum, 2016)

Scoring comments:

Lightness of this structure and clarity of the process makes it very attractive and even though the pavilion was only experimental, this approach shows significant potential. Stiffness and durability of the material is impressive and should definately be implemented in the building industry.
However, it also shows some fundamental flaws. Because of the fact, that is was experimental, it does not act as an integral part of the building - for example, installations placement would be impossible.
Moreover, this technology is not able to hold any loads than itself so multistorey structure carrying multiple loads is not in the range of this method. Along with this issue, span size is limited. Added to that, the structure is quite delicate and will not bear intense fatigue of multiple reconfigurations etc.
On the other hand, prices of both material and the robotic arm are very high. The latter could be treated as a tool for craftsmen although it is not a crucial one, rather an oddity.

2.61/4 final score

7 Cradle Molding Device

(Griffith et al., 2011)

product material	concrete mix *or* cob *or* adobe *or* poured earth
sup-porting material	low grade CDX plywood (moulds)
finishing needed?	yes
optional finishing	plastering system facades any traditional wall finishes
max. el. size [mm]	227 75 150
geom-etry options	2D
geom. file input	.dwg .dxf
precision of the machine	± 0.05 mm
material compo-nents	varies, with high toler-ance, also needs an equine rubber material for extraction of bricks
common applica-tion	Construction industry in underdeveloped countries or post disasters
manu-facturing comp.	-

Griffith et al. developed a technique which combines digital fabrication and low cost composite materials pouring. This method relies on identical moulds assembled from CNC lasered wooden elements, which is equipped with a layer of rubber material helping extracting the bricks. A solidifying material is poured into the moulds afterwards and since the idea was to avoid using professional tools the mould itself comes in a craddle shape what allows rocking the solidyfying brick, instead of using a vibrator. The moulds are reusable and reconfigurable in order to procude different typologies of bricks.

Designers claim that this method allows for high precision thanks to digital fabrication yet does not require high building of crafting skills and is very cheap. Also, use of high precision tools and clarity of the production process increaces quality of the built structures.

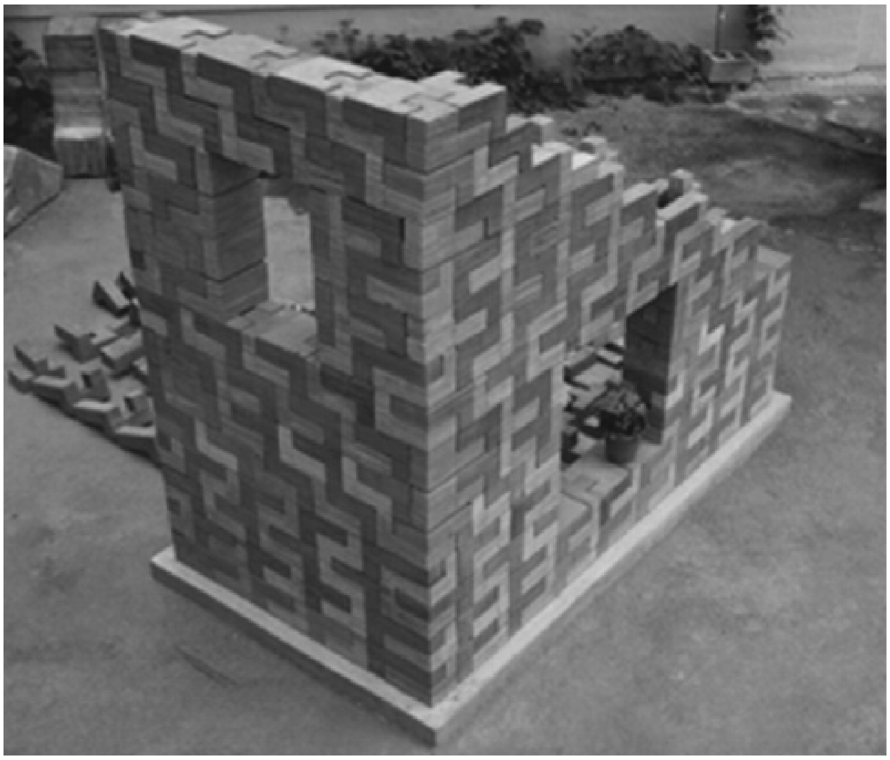


Fig. 18 - house assembly (Griffith et al., 2012)

fabrication process

stage 1 → mould elements are cut on a laser cutter

stage 2 → moulds are assembled and the rubber material is distributed inside

stage 3 → composite material is poured in moulds

stage 4 → material curing in moulds is being rocked

stage 5 → moulds disassembly

stage 6 → structure is assembled from cured bricks

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durabiliy (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteristics(II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

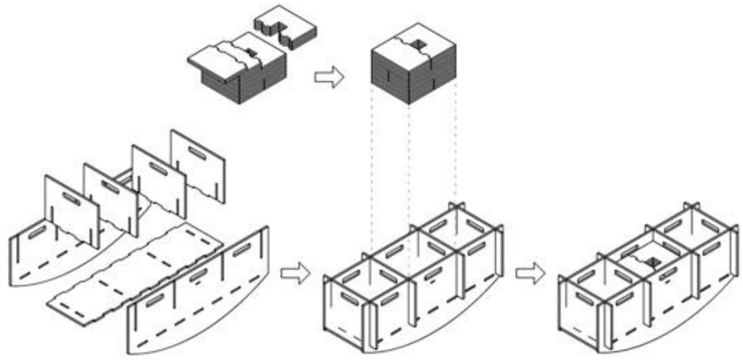


Fig. 19 - craddle rocker device (Griffith et al., 2012)

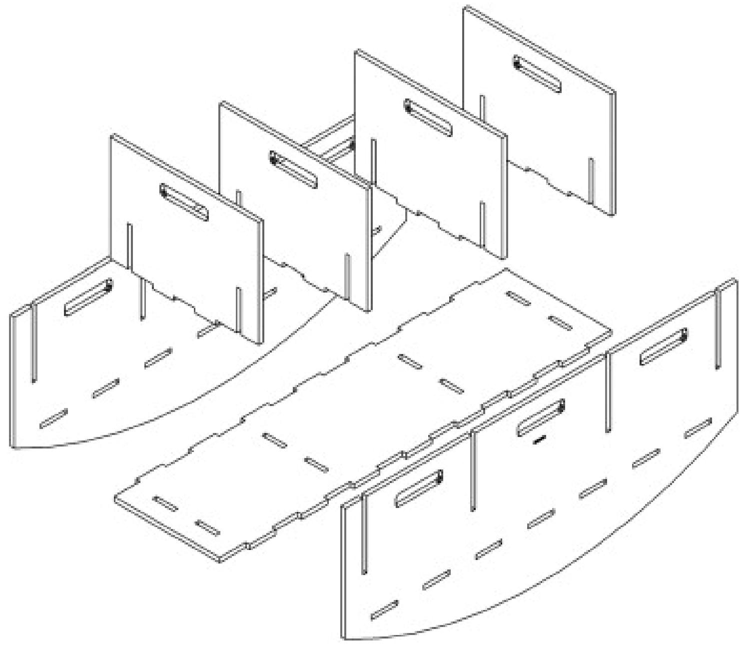


Fig. 20 - craddle rocker device exploded (Griffith et al., 2012)

Scoring comments:

Cradle molding device scores quite well, thanks to such parameters as clarity of process and use of easy tools and materials. It is easy to understand, low cost and environment friendly, while the moulds can be reused. Nature of this system also answers the needs for customizability and reconfiguration.

However, as well as previously mentioned Cast Formworks, this system is deisgned for low cost housing and not big scale, multifloor structures. Low resistance for loads make this system impossible to perform as a primary structure and cooperate with other elements. Also, price of the poured material is meant to be low and what that usually means is also low quality what affects fatigue durability.

2.97/4

final score

Investigated methods conclusions

In general, all the techniques which do not consider fixed joints or big fixed elements are better, thanks to higher reconfigurability. That takes CNC cut wood to the lead of this study. Also, not all techniques use common digital fabrication machines, used by many makers, what makes them far from accessible and easy to use. Examples of those can be seen in the first case study - Precast concrete elements from moulds fabricated using cnc moulding (Beorkrem, 2013), (Hauschild, Karzel & Hellstern, 2011) or D-Shape (Hauschild, Karzel & Hellstern, 2011), (Lim et al., 2011), (Dini et al., 2013). Moreover, those use concrete which is heavy when solidified and does not offer many possibilities for reconfiguration.

According to the scores of particular methods it seems that the best one considering this research has been developed by Stoutjesdijk (Stoutjesdijk, 2013).
However, this technique has a major flaw, which disqualifies is to serve as primary structure of a big scale building, carry big loads as columns or operate as wide span beams.

Therefore considering this research, this technology requires a material which is as easy in machining and lightweight as wood, but much stronger and durable.

It can be concluded, that a perfect method of digital fabrication would replace wood- with a stronger material for the structural parts of the building while any smaller elements like furniture, partition walls and all the equipment can remain as made from wood.

Fiberglass

In the serpentine pavillion designed by Bjarke Ingels Group in 2016 architects were experimenting with the possibilities of a composite materials and in particular - fiberglass.
The pavilion, which resembles a wall of bricks that has been “unzipped” to create a void inside, consists of around 1900 empty fibreglass boxes, which are attached by simple metal joints. The pavillion uses 3 different types of boxes in terms of wall thickness - on the bottom the walls are 10 mm thick, through 6 mm and finally the lightets - 3 mm at the top.

The fiberglass boxes composing BIG’s pavillion were produced ar the Middelfart factory of the Danish company Fiberline Composites, which usually manufactures composite structural profiles for buildings, bridges or wind turbine blades. The material used for the pavillion boxes was the Lay Light - a translucent composite of glass fibers and polyester resin. As the producer states - this material is as strong as steel but has only one fifth of its weight.

Fig. 21 - BIG’s serpentine pavillion interior (www.afasiaarchzine.com, 2016)

Fiberglass is a composite material - that means is it is consists of a combination of two different materials, neither of which can be used for construction purpose on its own. Composites has been well known for ages - straw mixes with clay or nowadays - steel reinforced concrete.

Reinforced plastics make a significant contribution to the composites that are used in the modern society. Fibre reinforced plastics can be divided into two categories:

- synthetic materials reinforced with short fibres - used mostly for injection moulding or plastic extrusion

- synthetic materials reinforced with long or continous fibres - used for large structures as tanks, ship beds or turbine blades.

In fibre reinforced composited, properties of the fibers deal with tensile and compressive loads, while the plastic (the matrix material) transfers shear.

Pros of composite materials comparing to traditional structural materials like for example steel are significant - thanks to low weight and thus low dead weight, particular components can show better performance. Because of being a composite material - the mixture and proportions can be designed specifically for needed load bearing capacity, while providing a number of extra advantages such as resistance to chemicals, electrical or thermal insulating properties.

Fig. 22 - Fibers feeding the production line (Fiberline, 2016)

Pultrusion

Fiberglass is manufactured in an automated production system which is called pultrusion. The mechanism od this method relies on a continual production of composite profiles with constant cross sections and material properties which are manufactured for specific purposes.

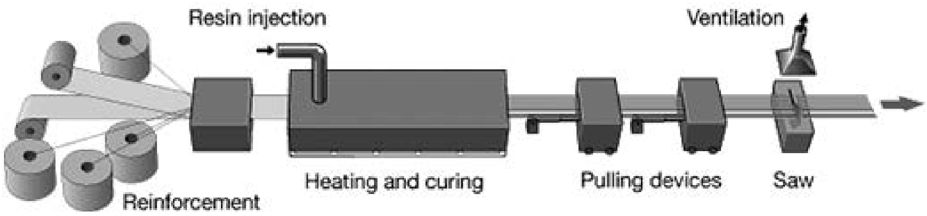


Fig. 23 - Fiberline pultrusion process diagram (Fiberline, 2016)

In case of Fiberline, their pultrusion process is done by continual reinforced material being pulled through a guide where the fibers are placed with precision in relation to the profile cross section. Then the fibres are led though processing equipment where they are impregnated with the resin matrix material. This combination is then pulled through a heated equipment which cures the profile in its final geometry. The final, fully cured profile, is then cut with a floating suspened saw which divides the profile into desired lenghts. Thanks to this process, there is no limitation on the profile or sheet lenght.

Reinforcement

The primary role of the reinforcement fibre in a composite material is based on the mechanical properties of fibres such as stiffness and strenght.

In composites in general, the most common types of fibers used for reinforcement are fiberglass, aramid fibres and carbon fibres. While fibreglass fibres presents as a good all-rounder, carbon fibre outstand with stiffness but also price. Aramid fibres allow for withstanding mechanical impacts. What is more, fibreglass composites and profiles made of it provide electrical insulation and electromagnetic transparency while carbon fibre profiles show electrical conduction.

Roving

Orientation and direction of the reinforcement fibres is of great importance for the properties of finished products considering load-bearing capacity.

Structural profiles are made from different types of mats and weaves (always a profiles uses both) in multiple configurations, depending on the expected load direction etc. Some mats types provide also better mechanical properties thanks to which bolting and bolts removal is possible, with no negative effect on the profile.

Fiberline, as an example, produces several types of complex weaves and mats.

Types of roving:

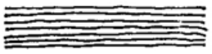


Fig. 24 - 1. unidirectional (Fiberline, 2016)

Fig 25 - 2. spun (Fiberline, 2016)

Fig 26 - 3. mock (Fiberline, 2016)

Types od mat:

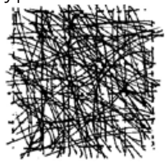


Fig 27 - 1. Continuous random fibre orientation (Fiberline, 2016)

Fig. 28 - 2. Weave 0º/90º (Fiberline, 2016)

Fig. 29 - 3. Complex 0º/90º weave + random fibre orientation (Fiberline, 2016)

Fig. 30 - 4. Multiax mat 0º/±45º (Fiberline, 2016)

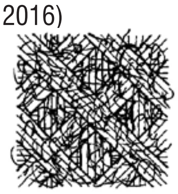


Fig. 31 - 5. Bidirectional complex 0º/±45º/90º weave + random fibre orientation (Fiberline, 2016)

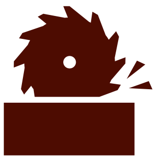
If considering replacing wood in the technology of puzzle - like assembled structures (Stoutjesdijk, 2013), the only way to implement fiberglass is to use it in sheets. Therefore, in the following part of this research, fiberglass sheets will be presented and investigated. It has to be stated, that fiberglass sheets have slightly worse properties than structural profiles according to Fiberline consultants (Folkmann and Malagic, 2016).

Fiberglass machining

Pultruded profiles and sheets can be machined with ease comparable to wood and thus, wood machining tools can be used. Steel machining tools are recommended when machining larger series of sheets, as wood tools will get under heavy fatigue due to abrasion from the reinforcement fibres.
Pultruded fiberglass profiles and sheets are elastic therefore all profiles should be protected from vibrations which occur while the process, especially when machining long profiles. Because of that, there is a need to ensure a fixed, vibration-free support and retension. In general - too fast cutting will occur in burry surfaces and imperfections of cut and will require sanding.

Imperfections (such as those which result in cracking in glass) will have an influence on the properties but the process used by a fiberglass manufacturer secures a high and stable quality. Profiles can be glued and fixed - unlike carbon fibre elements. However, it is recommended to replace any damaged element in order to maintain initial properties. Bolting and gluing is recommended for joints. The recommended glue should be a 2 part epoxy adhesive. Smaller damages can be repaired on site.

Any machining process on fiberglass causes dust, therefore any tool should have an exhaust mounted. Also, ordinary ventilation system will provide enough protection. There is no scientific study which indicated that this dust can be dangerous to health, however it can cause itching, breathing irritations or temporary skin rashes.

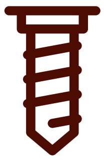


Cutting

Small amounts of material, or quick adjustments of profiles can be performed with a simple hacksaw or even handsaw. For long strait cuts a circular saw is recommended for best results. Also, a diamond blade is recommended. Sawing must be performed using diamond blades if large series of elements are to be cut. Also, it will allow for clean cuts withouth burring.
During sawing, the profile should be securede on a stable, vibration-free bed. The cutting speed should be 60 m/sec, and to achieve the best results, feed lightly. Too heavy feeding merely increases wear on the blade.

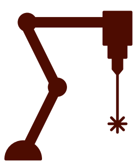
Grinding and deburring

Pultruded profiles can be deburred with sandpaper. It is recommended to use a belt grinder at high speed with slow advancement speed.



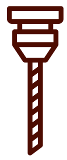
Drilling

Pultruded materials can be drilled with relative ease. An ordinary metal drillbit is suitable to bore individual holes or limited series of holes.
When drilling large amounts of holes a special drilling bit is recommended. Thanks to that a sharp hole rim without burr (also at the exit) can be achieved. This kind of bit is designed to give as low vibrations as possible when drilling perpendicular to the surface, what is an extra advantage when using power drills.
For drilling large holes, a spoon bit with a centre bit is recommended. Burr on hole rims can be avoided by drilling part-way through from one side of the profile, and then the rest of the way from the other side.



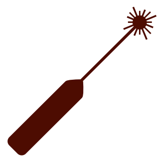
Laser cutting

Profiles can also be machined by laser cutting, using a protective gas such as argon.



Milling

Milling with a diamond cutter is recommended. In this type of machining, tools with a rake angle on the cutting edge of between 5° and 15° can be used. Feeding can be up to 0.5 mm/rev., and speeds of up to 1000 m/min. will give the best results. Too heavy feeding will cause unwanted heating of the surface and gives less satisfactory results. Mat type does no affect the result of milling, however the most effective are the mats with lowest weight per area.



Water jet cutting

Water jet cutting is used for cutting sheets and solid profiles of up to approximately 20 mm thickness. Using this technique on non-solid profiles can be problematic. The jet becomes diffused on cutting through the initial material and is therefore unable to cut the underlying material with sufficient accuracy.

product material	fiberglass
sup-porting material	polyester resin
finishing needed?	no: all Fiberline profiles have an overlay vail which protects the pro-files from corrosions and UV light and gives the profiles a smooth surface
max. el. size [mm]	width: 1220 lenght: ∞ thick.: n/a at least 30
geom-etry options	2.5 D
file for-mat	.dwg .dxf
machine precision	0.1 - 0.2 mm
common applica-tion	Construction industry
manu-facturing comp.	Fiberline Composites - material
min. thickness	3 mm
material density	1,8 kg/l
material weight	1800 kg/m³ 660 kg/m³ (bleech wood) 750 kg/m³ (plywood)
stiffness	24 GPa for profiles 17 GPa for sheets (3.5 - 3 GPa - plywood)
certifi-cates	for structural profiles: EN 13706, E17 and E23 exceeded for sheets (10mm, 20mm, 30mm): EN 13706: all require-ments from E17 and most values of E23 Allgemeine Bauauf-sichtliche Zulassung EBA
price	higher than wood/steel normally on the level of stainless steel 10 mm 1220 mm wide: € 180,00/m 20 mm 1220 mm wide: € 330,00/m 30 mm 1220 mm wide € 470,00/m at minimal 3000 m order + toolcosts around € 60.000
colours	light gray translucent

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durability (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteris-tics(II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

Fig. 32 - Sheet fiberglass material with 2.5 D engraved Fiberline logo - what confirms that wood-en friction locks are possible to be used also with this material (Fiberline, accessed 2016)

Scoring comments:

Comparing to other digital fabrication methods this hy-brid solution outclasses oth-ers, considering the numer-ical score. It merges all the advantages of puzzle system of Stoutjesdijk and adds to that outstanding structural durability and performance, which allows for building big scale structures.
Major disadvantages of using fiberglass in this method is the price and weight of the elements. Fiberglass, being 3 times heavier than plywood is acceptable, but might be cumbersome.

final score 3.53/4

4.00

conclusions

4.01 suggestions for further research

This research aimed at delivering framework for a shared work environment for emergent maker community which uses non standard entrepreneurship patterns as well as new manufacturing technologies.

Research about the target customer group has been conducted. It allowed for understanding of the client needs. Also, thanks to juxtaposition of interviewed makers and visited workshops it was possible to classify makers into generic profiles what can help while any design process based on this research, weather it considers customization or any adaptation to the needs. These profiles are: One Man Hobby, One Man Professional in Collaboration, Small Company, Medium Company of Makers and a Medium Company of Product Developers.

On the other hand this paper goes through history and theory of customization and mass customization in order to understand this phenomenon and help to decide which pattern suits best in case of this research. It allowed to arrive with a customization pattern inspired by theoretical approaches as well as commercial systems. Through an evaluation according to most important requirements basing on the users needs a system called Customer Driven Approach was chosen and adapted to architectural needs. It is relying on standardized elements from variety of which the user can pick and assemble their own final, custom item. In this architecture, this is divided into layers - modules, which compose spaces and are open source. These, compose fully customized work units for companies, which further on sum up as the whole interior of the workshop.

In order to materialize the system, a digital fabrication technique was looked for. Digital fabrication, as a mean already used by many makers delivers many benefits as a way to produce the building. Mostly proven methods were checked, but also those which show greater potential. Finally a hybrid solution is presented which merges a method known from one of case studies but enhances it with use of a innovative material. Pieter Stoutjesdijk's (2013) building system using CNC milled elements connected with friction locks has been chosen as the most promising according to evaluation upon requirements concluded during the research. However, as it uses wood in sheets as a material, it is limited to small scale of building, therefore for the structure elements fiberglass is proposed. This pultruded fiber-embedded polyester is proven to work as structure elements, is strong and stiff as steel and easy to machine as wood, what makes it perfect for purpose of this research.

Even though the aim was strict the outcome of this research can have other uses. Any building system based on this research can be also used as a bis scale reconfigurable structure for any desired purpose. It can answer for example the issue of vacant offices which could be readapted in 100% to new needs instead of being torn down. Any situation which requires a reconfigurable solution and does not accept structural limitation can consider this research.

This work had a certain time limitation therefore there are fields for improvement and broadening. Author of this research highlights especially topics as follows:

- physical implementation of fiberglass sheets into CNC milling technology based on Stoutjesdijk (2013) and Sass (2006), research by design on this material - technology connetion;

- research on performance and behaviour of fiberglass as (wooden) friction locks, also research on durability of such locks;

- research on performance and properties of beams and columns made from fiberglass elements - check if they meet E23 requirements as a complete building element;

- fatigue with time should also be researched, weather fiberglass wears off quickly when assembled and disassembled multiple times. Also, the authoer suggests to check if it is more durable mechanically comparing to wood;

- how does the invented system perform in a environment for which it was designed - does it really work with semi-qualified workers?;

- practical check of the building process - the author of this research had a chance to work on two projects alike - Nadia Remmerswaal's Cast Formwork System protytype assembly (Remmerswaal, 2015) and his own design realisation and based on that experience is aware that some discoveries occur only in practice and the assembly phase;

- parametrization of the process and use of algorythmic controll over the users requirements, accordingly to other customization case studies instead of using users profiles, which will allow for more tailored approach. However, as it was stated before, this is not a priority, as most of the requirements repeat, but change in scale.

Author of this work suggests the following steps prior to design based on this research:

- a complete list of items and elements which have to be designed should be prepared, in order to utilize the profiles od makers sufficiently
- the designer should address also the potential that this sort of building might deliver and think what other function will it deliver to the surrouding city;
- additional benefits for the neighbourhood should be considered. A community of makers is not only a working group of people but an extremely creative community which can enhance social life in any place;
- author strongly suggests to design not only the architeture but also the societal structure inside. In other words, the curation of work and relations between tenants accordingly to the research about makers and many inspirations given in the two first databases provided;
- as for the tools of the design - it is suggested to use parametric design tools in order to enhance the controll over the project and raise efficiency.

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list of figures

appendix 1.

users database

Each design is unique as well as each designer is. From small hobby entrepreneurs that don't rely financially on their work, through independent artists to finally full professional product developing companies working on complex products. Each of those is diferrent and approaches their work from a special angle. So are their needs, habits and requirements for workshops. What is substantial in this case is to know what patterns are common.

Therefore for the needs of this research 10 makers from Delft, Eindhoven, Amsterdam and Barcelona have been interviewed. Author visited most of their workshops to understand how they work and what they do. A set of questions formed in a survey was prepared to aquire knowlegde about them. These 25 questions helped both in forming profiles of potential customers as well as aquiring their strict requirements for spaces in which they work. Also, these interviews allowed to understand how collabioration patterns are creates and how such ventures work.


own photography

1.

Buttonius

Puzzles & Plastics

Peter Knoppers

“The most important thing when you design is to live among the machines”

Peter creates impressive 3d puzzles that can trick anybodys mind. He makes them mostly for events and gatherings of hobby puzzle assemblers and sometimes ships them to clients.

He is the only person working in his company, although he sometimes organizes small workshops or collaborates with guests.

His workshop shares the space of his home, it’s located at the second floor in a small room which has around 12sqm.

He uses his workshop often to produce some items for his home or to fix broken things. He says that the fact that the workshop is an intergral part of his home is extremely beneficial for his house and also for his business. No need for commuting motivates him and immediate access to the workshop allows him to materialize any idea instantly.

Image source: http://www.bad-huys.nl/

2.
Ben Hohmann
furniture designer

Hi I'm Ben Hohmann, a no-nonsense creative maker with an eye for inter-activeness, materials and detail. - *benhohmann.nl*

Peter is a TU Delft graduate at track of Architecture. His dissatisfaction with being an architect and the lack of material understanting and labour tought in Delft pushed him towards his real love - crafstmanship.

Peter bridges different realities. An example could be his magnificent design for Heirloominescence - a cupboard with history. Extraordinary design or rather reuse intertwines with unique history - cupboard which solitarily survived WWII bombing has special value for its owner therefore needed a radical refurbrishment.

He is a single craftsmen in his company but he often collaborates and is involved in cooperative projects.

His workshop shares the space of Sectie-C in Eindhoven, which is located in an industrial hall and used by other makers and craftsmen. He has two workshops - one is clean and intended as the finish workshop while the second is a dirty works workshop - for welding, cutting etc.

own photography

3.
Laserbeest
Laser cutting and design

Pieter Raat

"We actually buy a new laser cutter every year"

Pieter is a TU Delft graduate at track of Architecture as well. His journey with digital fabrication and crafting started along with the 2008 financial crysis when he and his friends were looking for new ways of creating income. This is how Laserbeest was born.

Laserbeest is a small company which is composed of three partners and two employees. They mostly take orderd for cutting and advise with laser cut projects but also design and make prizes and statues.

Laserbeest workshop is located in Delft. Important and an interesting thing is that the workshop is connected to a space which serves as a place for customers to consult their designs to be cut but also a coworking space - each of the partners has an architectural company registered in that place.

own photography

4.
Fabrique3D
Product development

Theo Wolters

"In business there is no financial collaboration. Business is like jungle - only the fittest survive."

Theo graduated at TU Delft at Industrial Design faculty and immediately after finishing his studies he established Fabrique with his two collegues. After some time their paths split but all of them decided to stay under one name of the company, which now provides completely different services.
Theo therefore has a very serious and practical approach to business and helped me a lot with understanding how a collaboration should work. No financial collaboratin, only rules of coworking spaces can apply.

Fabrique is a big company, employing around 100 people all over the Netherlands. They have twoj offices in Delft and one of them is dedicated to product design and development.

Fabrique3d uses rapid prototyping and scientific product testing. For that they use two places - a small rapid prototyping workshop directly connected to their office and a hall for tests and material supplies.

own photography

5.
Joan Vellve Rafecas
Designer

Collaboration-O

Joan Vellvé Rafecas looks at establishing connections between the diverse practices of the design field. Based on a research method development presents outcomes as products, interventions, furniture or strategies.

Joan looks for transparency and understanding of the material and production processes as starting points to generate unexpected but simple outcomes.
- collaboration-o.com

Collaboration-O is a collective of artists housed in an industrial hall in Sectie-C, Eindhoven. Their creative activities is very wide and span across the fields of design and art, and specificly industrial design, installations, interactive art and interventions.

What is interesting and very inspiring about Collaboration-O workshop is the way of dealing with the space. To maximize use of the space tenants combine layouts of the spaces using diferent types of mezzanines, split levels and antresoles. That allows to use diferent heights of the space according to needs and destinations and divide into various characters of space and program.

6.
Sander Wassink
Designer and artist

Collaboration-O

"What is the most important thing in such a collaboration? Flat structure. No hierarchy."

Sander Wassink is an artist and designer who encourages us to reconsider our ideas of beauty, aesthetic value, status. How can we reconsider what is important and what is desirable to include notions of history, memory and the preservation of a past which is slipping away. Amid new construction, new production, and constant proliferation of new forms and facades, Wassink turns his attention to the discarded, the abandoned, the left over and attempts to reimagine what can be done with the already partially formed. What new possibilities exist in the surfaces and materials that are half-built or half-destroyed. Whether his object is the partly demolished facade of an abandoned building, or the everyday detritus from our over productive culture, Wassink asks what new forms and new visions of beauty already exist to be discovered and appreciated.
-sanderwassink.nl

own photography

7.
Kirsten Peerdeman
Graphic designer

Atelier Indrukwekkend

Kirsten is a fine arts graduate who specializes in graphic design using oldschool printing techniques. All of her tools are completely mechanical and use no electricity.

She produces diferrent cards, posters and other paperworks, all are handmade. She sells that in a separate part of her studio. She employs one person who helps her with making her products.

Apart from this she curates graphic design workshops and teaches participants how to use these classic machines. She is one of the few vintage manufacturers in the whole country.

own photography

8.
Daniel Marks
Jewelry designer

M-Edelsmeden & design

Mark is the head of the family business which is located in one of the row houses in Delft.

His company designs jewelry and sells it along with pieces from other designers.

Their workshop is quite unusual - it is located undregroudn and has no daylight at all. It is mostly a because of limited space in their office, and the fact that the store has to be in the ground floor. However, as Mark says - no daylight is not an issue for him. What is more - the lack of windows provides security, which a jewelry workshop needs, even though they don’t particularily store much valuable materials.


Image source: http://www.collaboration-o.com/

9.
Tiddo Bakker
Designer

Collaboration-O

Tiddo is one of the founders of Collaboration-O and was a key asset for me when considering topics of cooperation between makers and craftsmen.

He’s designing dynamic and interactive scuptures and installations along with interiors and more architectural designs when collaborating with the rest of Collaboration-O team. The collective gets a lot of assignments as a group, apart from individual orders.


own photography

10.
Anne Ruiter
Designer

Tjielp Design/Maakbaar

Anna is involved in very wide cariety of design activities - from small items like jewelry, through furniture to finally interior projects. She doesn't use her own workshop, her projects are brought to live in Maakbaar - fablab and community of makers in Delft, where she actively participates in many collaborations. Apart from Maakbaar, her designs are often realized using Shapeways services.

Makers summary

Makers summed up

The point of this database is to understand needs and habits of makers. A summarized parameters study will help to notice patterns and common characteristics of designers ways of working.

That will allow for a classification of certain makers into generic profiles which will allow to work on mass customization of this research. That will allow to understand what directions of customizability should be focused on and what groups need which parameters variable.

icons explanation:

a. product size:
- 1/4 toy size
- 2/4 small furniture size
- 3/4 big furniture size
- 4/4 structural element size

b. storage size:
- 1/4 2-5 m^2
- 2/4 5-10 m^2
- 3/4 10-20 m^2
- 4/4 >20m^2

c. customers visiting:
- 1/4 1-4/week
- 2/4 4-8/week
- 3/4 8-15/week
- 4/4 >15 weekly

professional, main income source

hobby, not the main income source

value	x

index in this box indicates to which profile is this user data assigned. That shows where certain maker was finally assigned.

value	x

if the box is filled that means that this particular data is meeting the common trend in the group (or just being diferent even though it is the same profile - case of group 4). That shows what are the common trends for a certain profile and if a certain maker is following this trend or not.

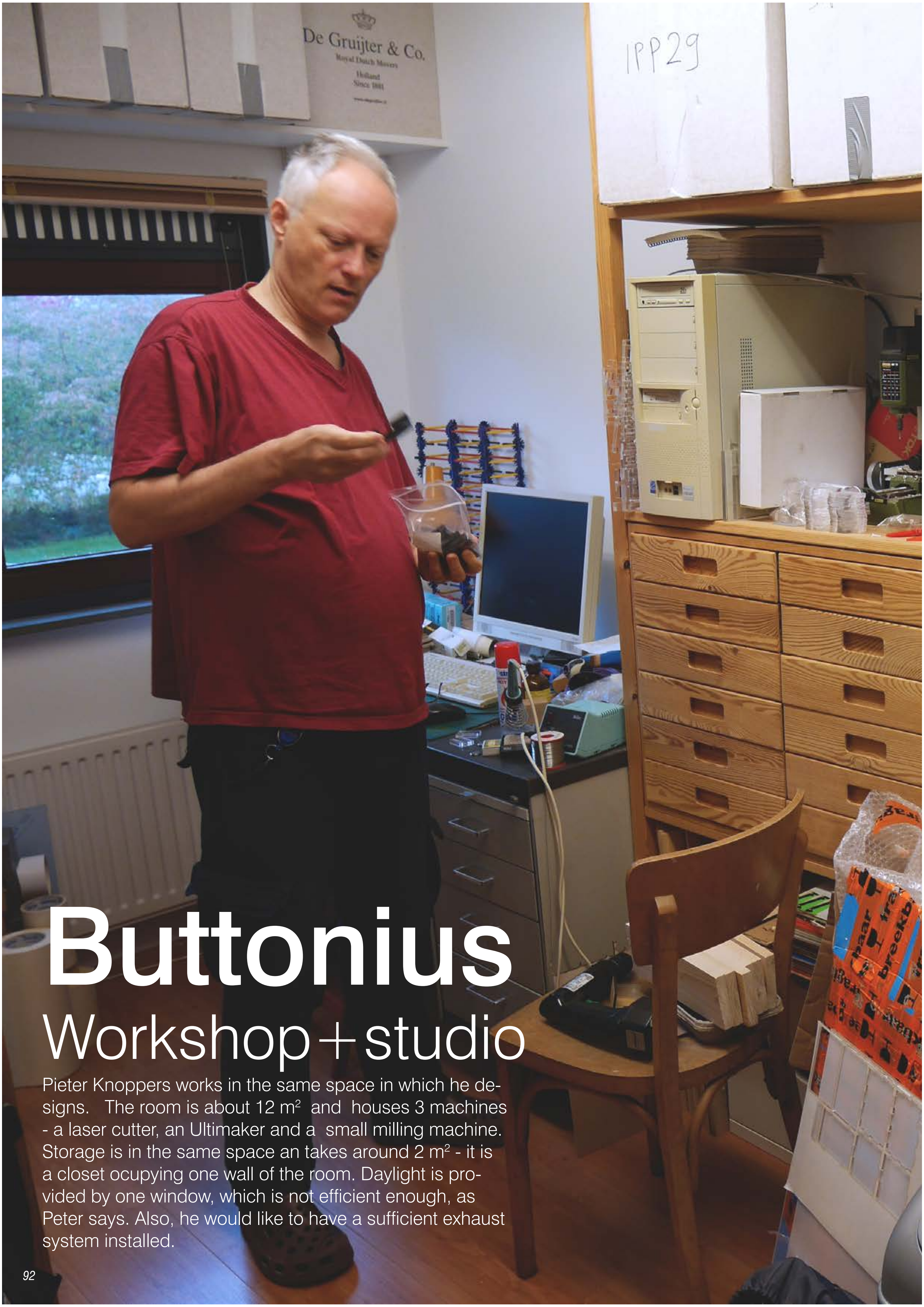
	1. M 01 Peter Knoppers **Buttonius**	2. M 02 **Ben Hohmann**	3. M 03 Pieter Raat **Laserbeest**	4. M 04 Theo Wolters **Fabrique3d**	5. M 05 **Joan Vellve** **Rafecas**
activity descrip-tion	3d puzzles producer	furniture and industrial design	laser cutting service	product design and develop-ment	furniture and industrial design
single/ how many?	[1] one man company	[2] one man company	[3] 3 partners 2 employees	[4] 3 partners 100 employees	[2] one man company
collab.? single?	[1] single	[2] collab occa-sionally	[3] Laserbeest - single cowork - collab	[4] 3 companies under one name	[2] collab (Collaboration-O)
location	Delft prv. apartment	Eindhoven Sectie-C	Delft coworking	Delft Amsterdam Rotterdam	Eindhoven (Collab-O, Sectie-C)
amount of ma-chines	[1] 3	[2] 3	[3] 5	[4] 3 + testing site	[2] 5
variety of ma-chines	[1] II	[2] III	[3] I	[4] III+	[2] IIII
demand [m²]	[1] 20	[2] 100	[3] 120 +80 (cowork)	[4] 120 testing +20 (rapid prototyping)	[2] 40
addition-al rooms	[1] -	[2] - dirty workshop - clean workshop - store - design office	[3] - dirty workshop - clean workshop - store - design office	[4] - dirty workshop - clean workshop - store - design office	[2] - general space - design office
selling at place?	[1] □	[2] ■	[3] ■□	[4] □	[2] □
anybody visiting?	[1] guests to design toghether, seldomly	[2] customers	[3] customers (laser and arch)	[4] customers	[2] customers
pro/ hobby?	[1]	[2]	[3]	[4]	[2]
how big are prod-ucts?	[1] ■□ / □□	[2] ■■ / ■□	[3] ■■ / □□	[4] ■■ / ■■	[2] ■■ / □□
how big is the storage?	[1] ■□ / □□	[2] ■■ / ■■	[3] ■■ / ■□	[4] ■■ / □□	[2] ■■ / □□
how many custom.?	[1] ■□ / □□	[2] ■■ / □□	[3] ■■ / ■■	[4] ■■ / □□	[2] ■■ / □□
result: product/ service?	[1] product	[2] product	[3] service + product	[4] service + product	[2] product

6. M 06 Neda Tozija **Transfodesign**	7. M 07 **Tiddo Bakker** Collaboration-O	8. M 08 Anna Ruiter **Tjielp design**	9. M 09 **Medelsmeden&design**	10. M 10 Kirsten Peerdeman **Atelier Indrukwekkend**	11. M 11 Pieter Stoutjesdijk **TheNewMakers**
furniture and industrial design	furniture and industrial design, dynamic	designer	jewelry designer	prints and graphic design	CNC various designs
3 partners	one man company	one man company	4 employees family business	3 employees	8 employees
collaborating	collab (Collaboration-O)	single	single	single	Collaboration (Ecoboards)
Barcelona	Eindhoven (Collab-O, Sectie-C)	Delft Maakbaar	Delft	Delft	Delft
10	5	3	5	7	2
300	60	20	50	60	700
- workshop space - design office - showroom - cleaning, changing	- general space - design office	-	store	- workshops studio	- workshop - design office - storage
□	□	□	■	■	□
architect and designers	customers	-	customers	customers workshops attendands	for cnc cutting
■■ □□	■■ ■□	■■ □□	■□ □□	■□ □□	■■ ■■
■■ □□	■■ □□	■■ □□	□□ □□	■□ □□	■■ ■■
■■ □□	■■ □□	■□ □□	■■ ■■	■■ ■□	■■ □□
product	product	product	product	product	product + service

appendix 2.

workshops database

To know the requirements of possible users there is no other way than direct talking to them and seeing their workspaces. There is no literature or studies on craftsmen needs and workshops requirements, unless these are industrial and big scale. In this case the only way to arrive with conclusions is purely practical observation and comparison of workshops and craftsmen.



Buttonius

Workshop+studio

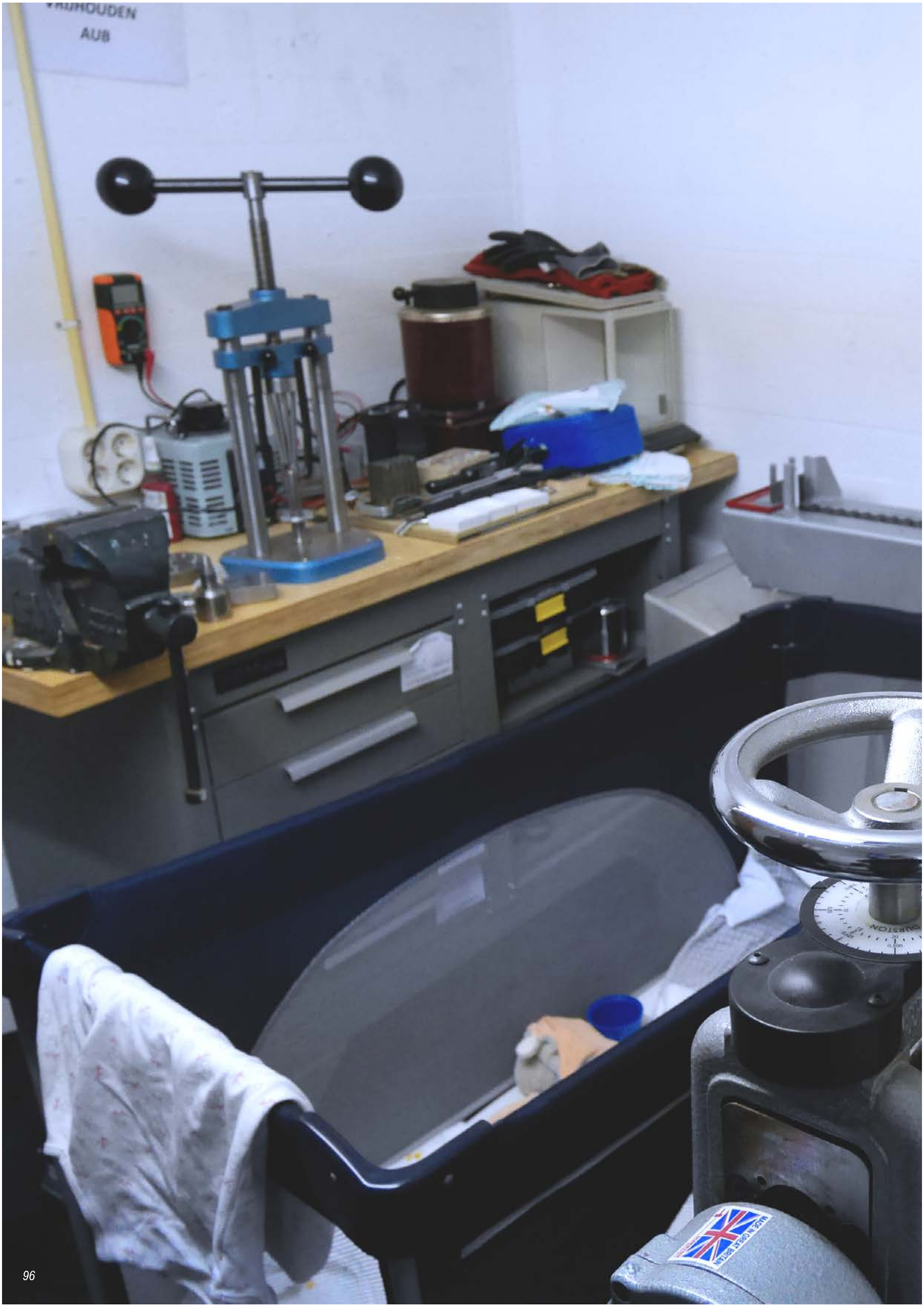
Pieter Knoppers works in the same space in which he designs. The room is about 12 m^2 and houses 3 machines - a laser cutter, an Ultimaker and a small milling machine. Storage is in the same space an takes around 2 m^2 - it is a closet ocupying one wall of the room. Daylight is provided by one window, which is not efficient enough, as Peter says. Also, he would like to have a sufficient exhaust system installed.


Puzzles
Puzz
mostly
Stries
DROSTDY-HOF
De Gru

Atelier Indrukwekkend

Workshop main space

Kirsten Peerdeman, the company founder and artist rents a typical Delft row house. Groundfloor is shared b y the workshop connected to the shop. Further is located the design studio and office. Privacy of the spaces advanced along the depth of location inside the building. The 1st floor is Kirsten's house.


AUB

M-edelsmeden + design

Workshop basement

Workshop is mainly located in the basement and has no daylight. As this is a jewelry workshop, quite often the supplies are valuable so this location is on the other hand an asset. Groundfloor is occupied by the shop and desk for the jewelry maker.

Laserbeest

Workshop main space

Laserbeest is equipped in with 5 laser cutters which are customized by themself - they changed the beds on which material sheets are placed (from the default, dense, honeycomb deck to simple beams with quite big spacing) in order to provide better final quality. Their machines are air cooled what was also their own modification. Because of that they need 3 additional rooms - air filter, compressor and electricity controler room.


FRANK
SOCIAL
IMPACT
AWARD

Laserbeest

Workshop main space

Laserbeest stores quite serious amounts of material in their workshop. Two impressive racks cover a half of the area, and they plan to build one more. Lost space is not the only issue - this kind of material is flammable, therefore special precautions and technical installations are required. The very end of the workshop has daylight - because of that the desk for assebly and manual work is located there.

Maakbaar

Workshop main space

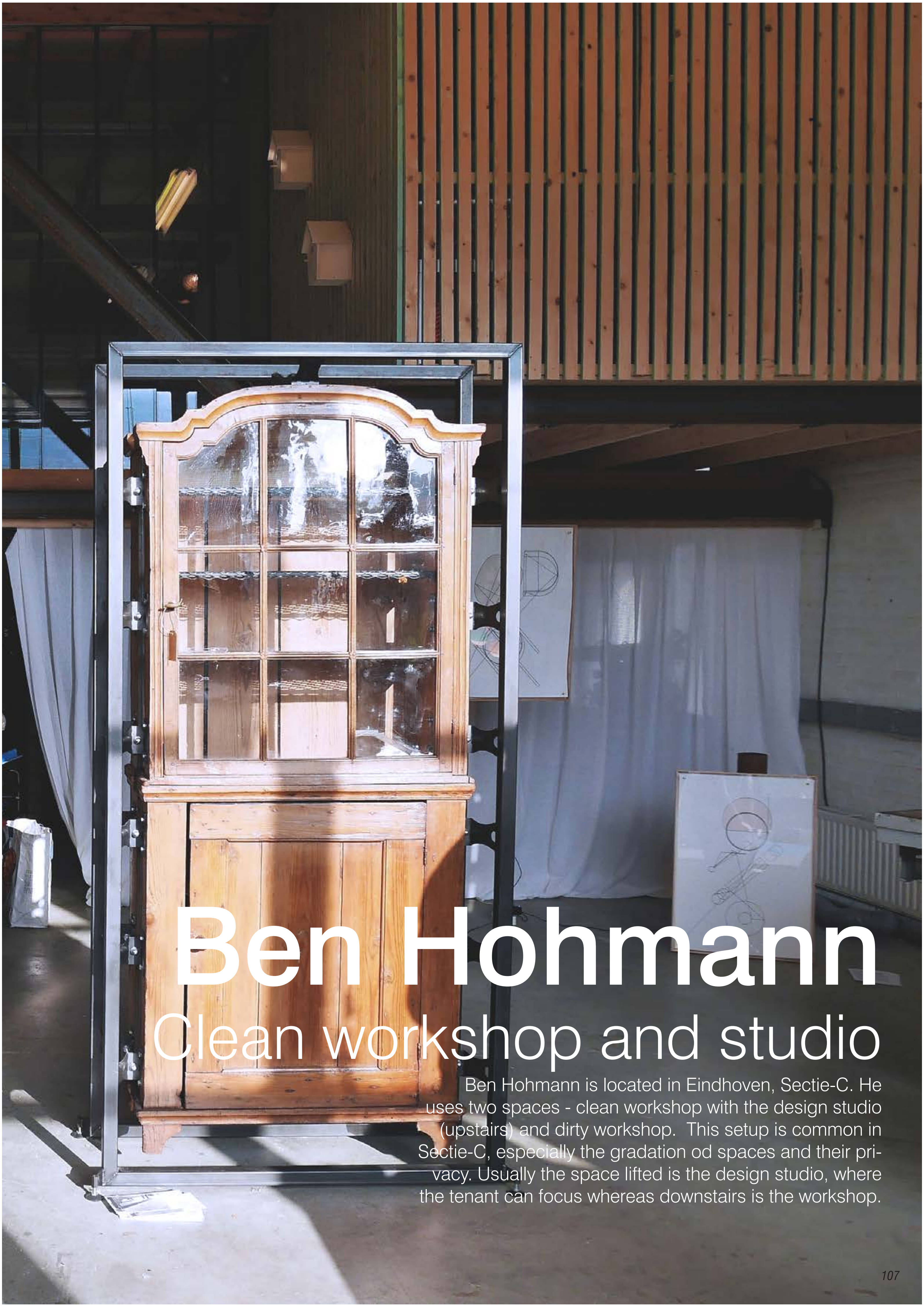
Maakbaar is a typical fablab located in Delft. The space is quite small and located on the first floor - machines (3 laser cutters) had to be lifted and entered the room throughtthe windows. One good value of the space are the big windows, providing effective illumination with daylight. Main workshop space is connected to coworking space for designers.

Fabrique

Open space

Fabrique does not share the space with any machines. There is a small rapid prototyping room along main working space but all the main tests on products is in another building across an inside street. Also, the developed products are produced not on the place.

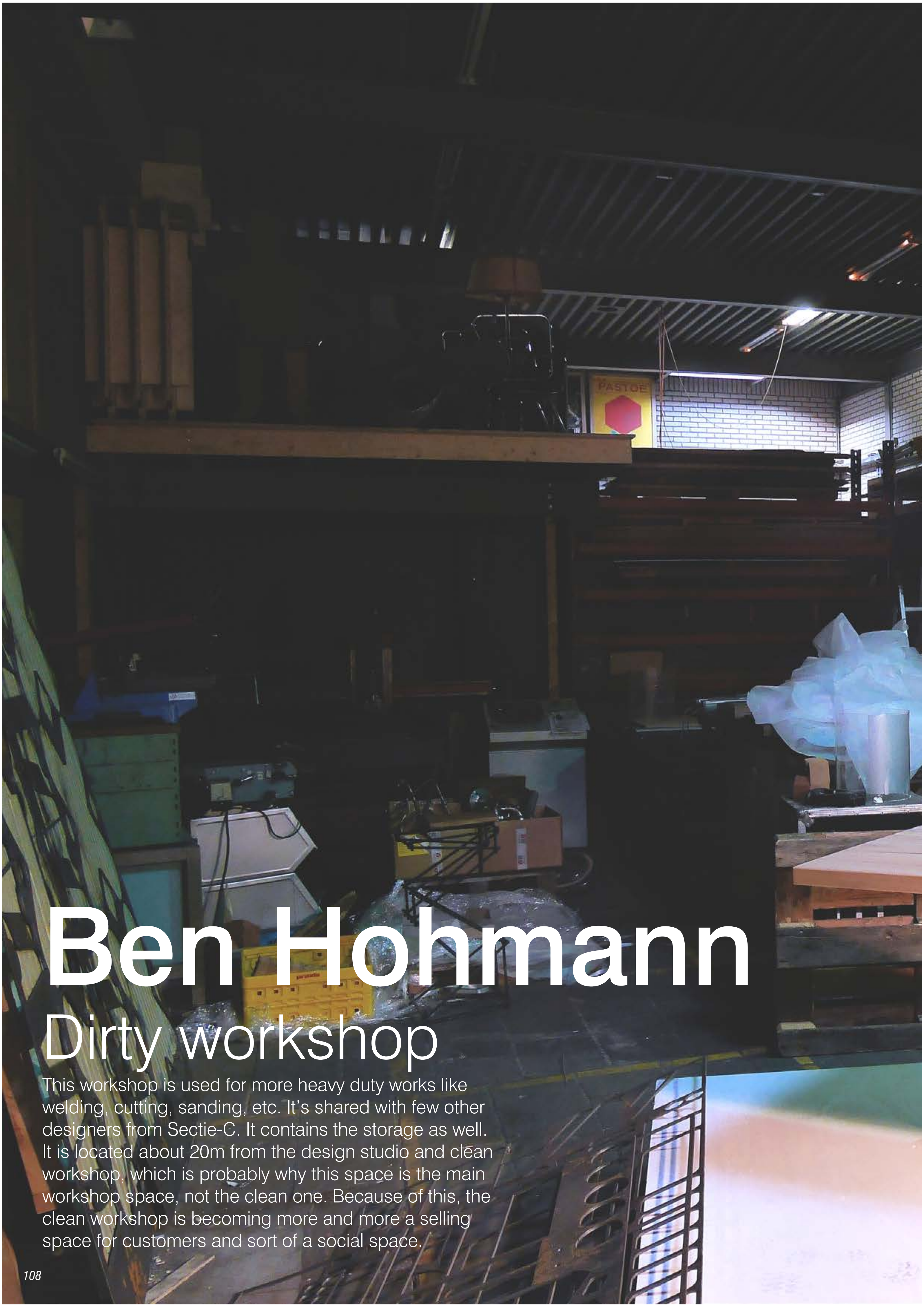

Kedeng Kedeng oehoe



Ben Hohmann

Clean workshop and studio

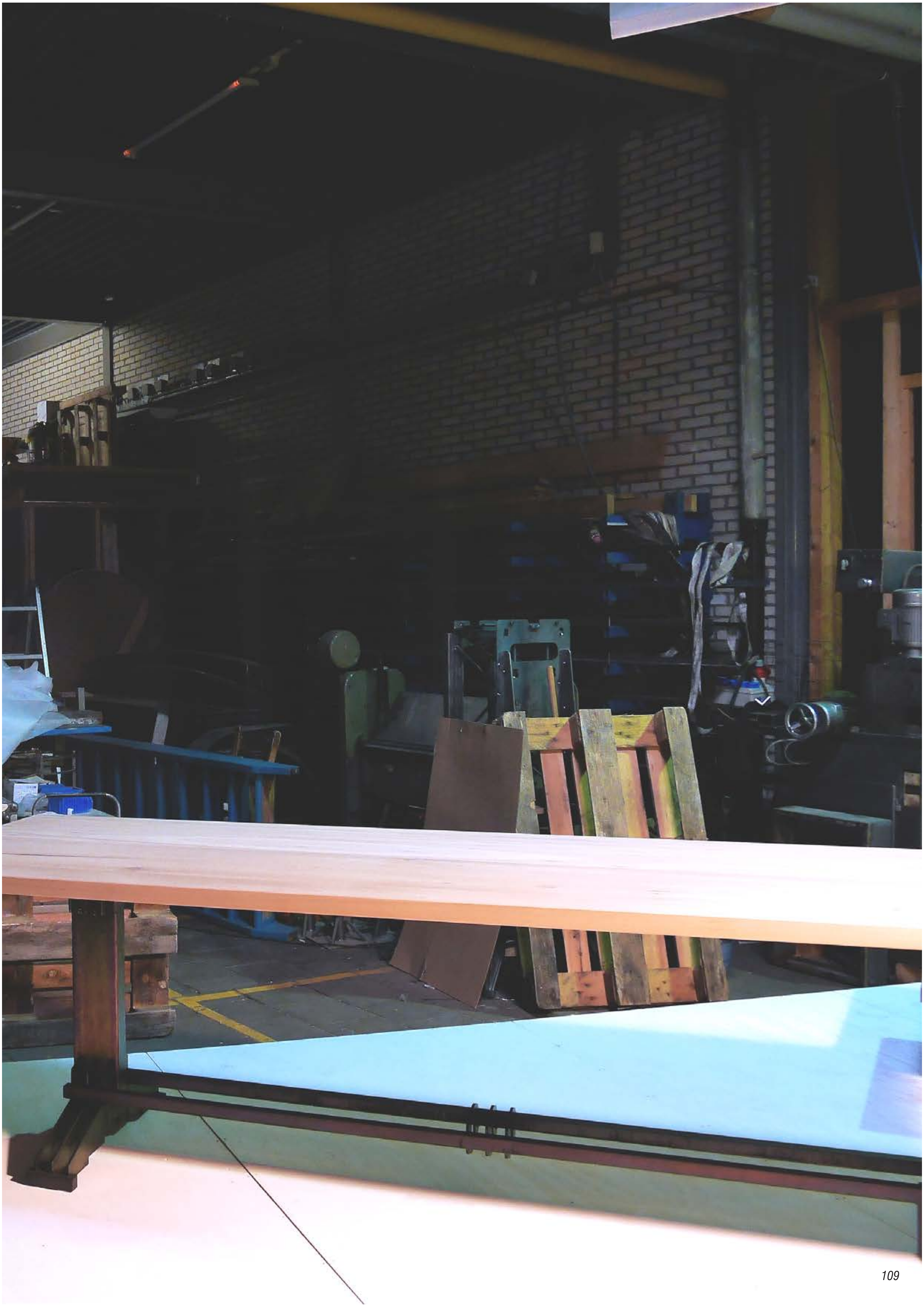
Ben Hohmann is located in Eindhoven, Sectie-C. He uses two spaces - clean workshop with the design studio (upstairs) and dirty workshop. This setup is common in Sectie-C, especially the gradation od spaces and their privacy. Usually the space lifted is the design studio, where the tenant can focus whereas downstairs is the workshop.



Ben Hohmann

Dirty workshop

This workshop is used for more heavy duty works like welding, cutting, sanding, etc. It's shared with few other designers from Sectie-C. It contains the storage as well. It is located about 20m from the design studio and clean workshop, which is probably why this space is the main workshop space, not the clean one. Because of this, the clean workshop is becoming more and more a selling space for customers and sort of a social space.



Digifab

Workshop + design office

What is interesting about this space is that each machine has a sort of private room. The big space of the former industrial hall of Sectie-C is filled with boxes for machines. The general space (right hand side) is the biggest box and contains studio and two laser cutters.

Collaboration-O

General space + studios

Collaboration-O is a perfect example of joined effort of makers, craftsmen and artists. This coop is located in industrial hall in Sectie-C and is using high space for at two levels, as Ben Hohmann case. Here we see exhibition prepared for Dutch Design Week 2016 located under lifted boxes with design studios. Yellow lines indicate boundaries of areas that are owned by designers. Between the boundaries is the general space, available for everybody.


YAMAHA

Collaboration-O

General space + studios

The general space is where the shared machines are located. Membership requires monthly fees but that allows to decide about everything in the Collaboration-O. The hierarchy is flat and there is no leader or board. Every new member is equal with the old ones and owes machines the same as others and has equal rights for having remarks about the space or cooperation working methods.


studio
Remy

Collaboration-O

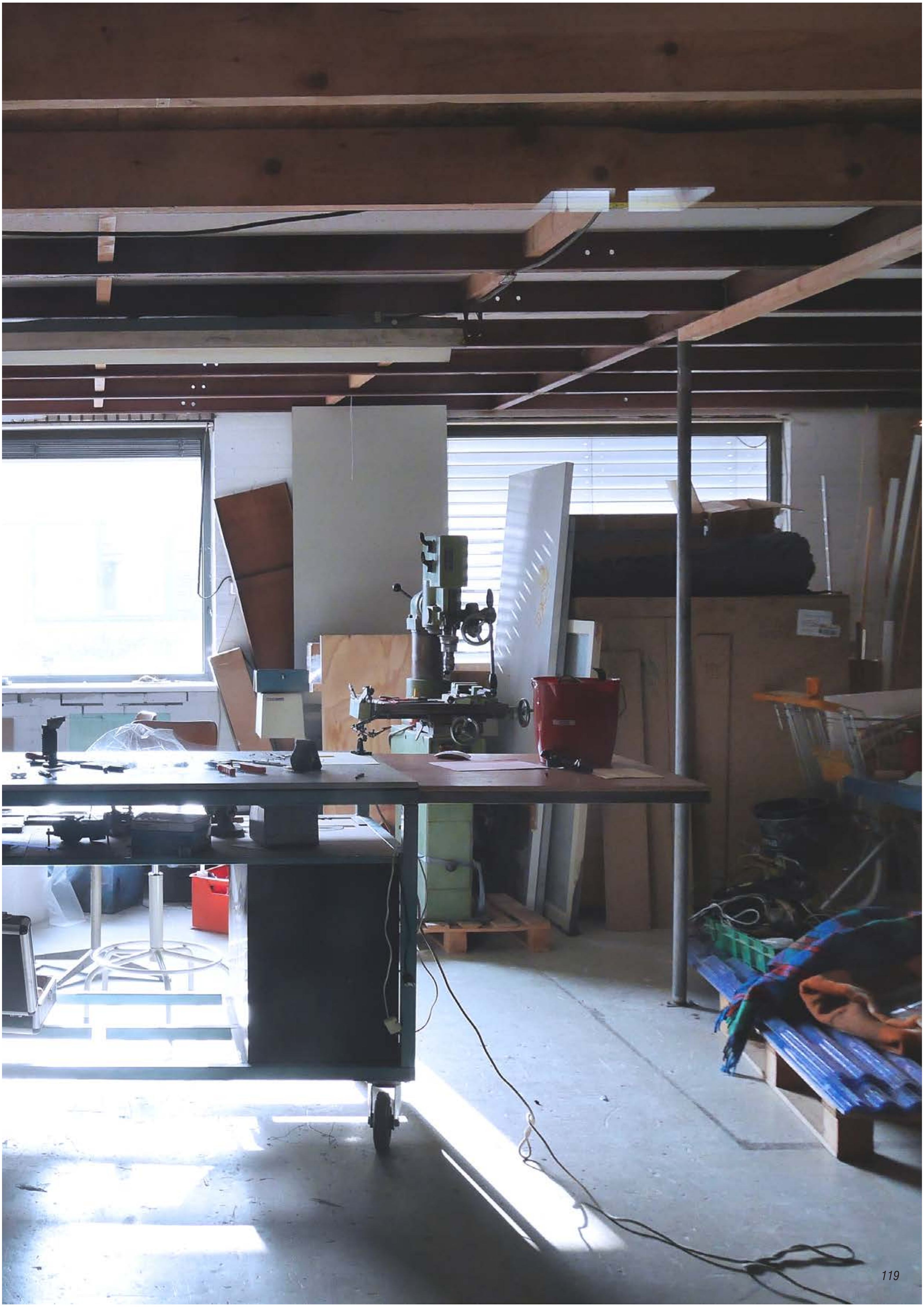
Private workshop space

Workspace in Collaboration-O is divided into 3 levels of privacy. The first was already mentioned general space in which all the shared machines are located. This picture however, shows the space assigned for one designer and used by them separately. It's not disconnected from the general space, but it is clear that only the owner works here.

Collaboration-O

Private workshops

In this case the private workshop is disconnected from the general space with a glass wall, which provides more intimacy and silence allowing the owner to focus and work on more detailed tasks. Above is the design studio, the most private part of the collaborations setup. What enhances privacy is that the only way to get there is with the steps, what is a sort of obstacle which first has to be met before getting upstairs.




scm
3/5

Spidersigns

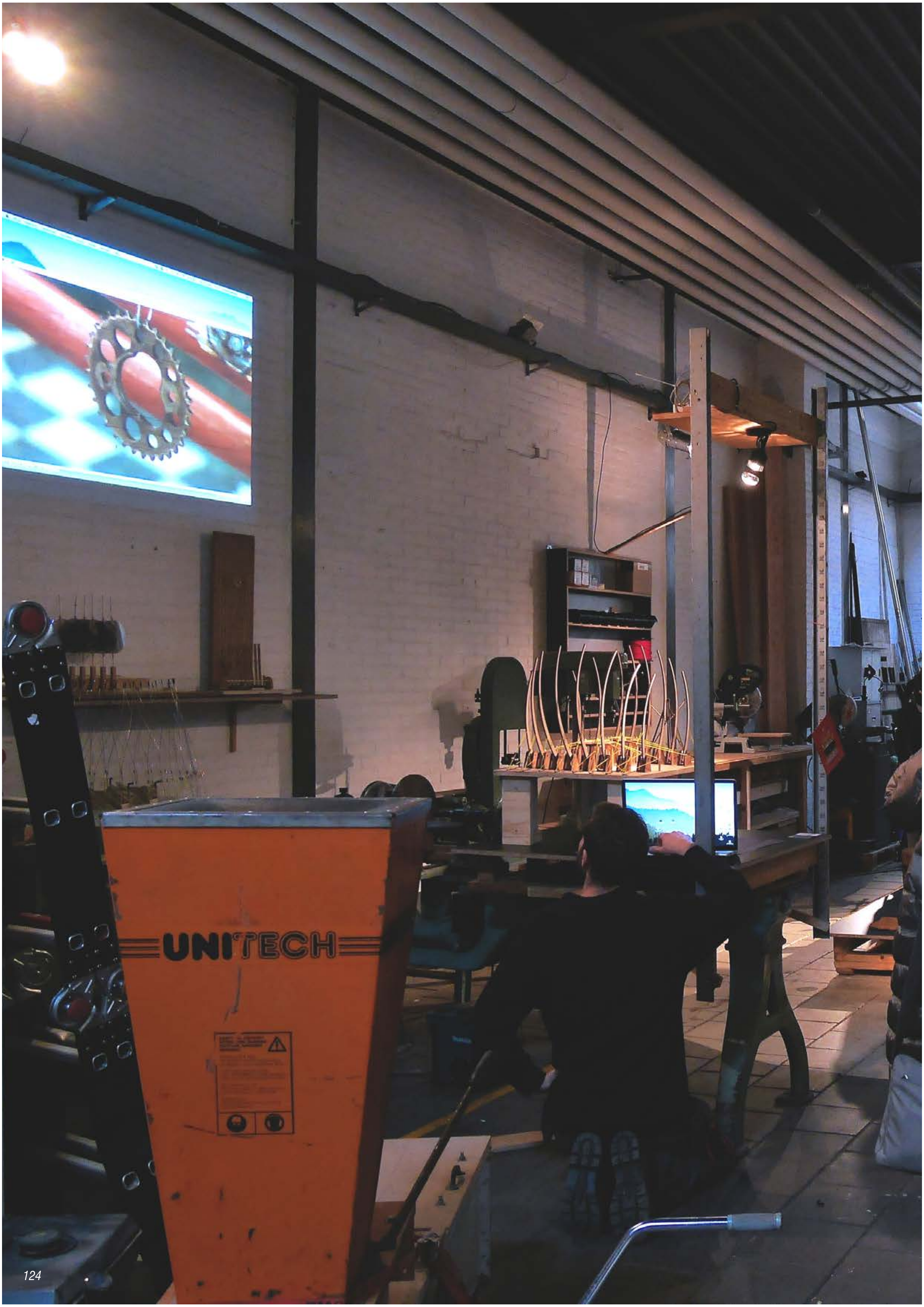
Private workshops

This studio uses a similar setup to two others mentioned before, even though it is located in a diferrent building. Workshop is located on the groundfloor and has a big door for receiving supplies and sending products made in the studio. The design studio is located above the ground again and contains also leisure space.

Spidersigns

Storage

When area is limited the best way to store supplies like flat material sheets is a vertical position. However that needs a high ceiling in the workshop room.


UNITECH

Omvorm-verdeelfabriek Boedelbank

Workshop

As typicall for Sectie-C the design studio is located above ground and the workshop beneath. The only space touched with daylight is visible on the picture on the right side - deep inside the workshop. There also is located the desk for detailed works.


WERK

Werkplaatswerk

Craftsmen coworking space

Along the Collaboration-O this is a perfect example of designers working in a shared space, for craftsmen sharing machines and supporting each others. The workshops are located on the groundfloor while design studio is a typical coworking space lifted above the workshops.

The New Makers

Workshop

This company makers all scales of products, including homes. Therefore the area of this area is much bigger than any other visited - 600 m². The central area of the workshop is the CNC drill. Top level machine is of industrial size and comes with additional technical appliances - computer (white tower on right), electrical control (hall corner, right side from comp.) and air filter and exhaust - located in the high tower on the right hand side.


RECORD 220
scm
Kelfort


medio

The New Makers
Workshop

This picture shows what is hidden in the aluminmum tower. Air filter is 4m high and is prefferably closed off because of the noise that it produces. Another device that is crucial for an industrial CNC milling machine is a compressor which also needs to be closed because of the noise.

The New Makers

Manual workshop

Even though the company makes digitally fabricated products a manual workshop with a desk and traditional tools is alweays needed. This one is also equipped with an exhaust system preventing dust and wood powder pollute the workshop air.
Setup of the workshop is reconfigurable as the modules are based on wheels.


FABSTORE
ECOBOARDS
FABFAC
LUCITE
Glitsa
LIJM
KIT
PUR

The New Makers

Storage

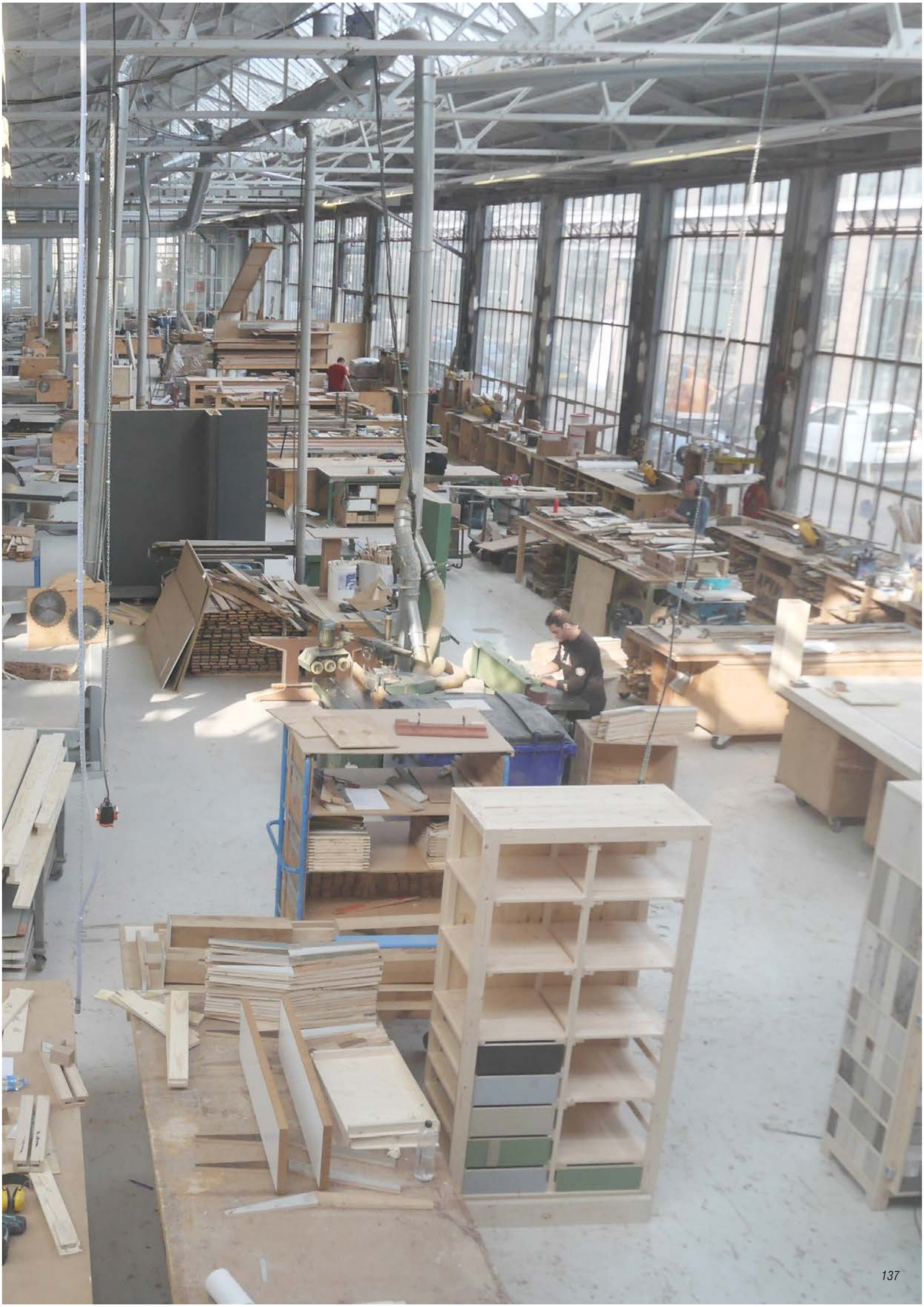
The deepest part of the workshop is a shared storage. Material sheeys are stored horizontally as the area is not a concern. Sheets are delivered to the machine using a forklift.

What is crucial here is the production flow - in this works materials delivery and product collection cross, which is an error.

Piet Hein Eek

Workshop

This hall is an industrial furniture workshop. Not exactly applicable for my consideration however some elements like storage patterns and supply chain are inspirational.



Workshops parameters summarized

The point of this database is to understand requirements for workshops, depending on certain groups of makers.
Extensive parameters have been included and compared, providing a valuable range of information, allowing further design to be tailored to customers needs.

icons explanation:

TABLE 1, p. 140.

floors character

type 1. type 2.

floors height

-/+ 6.0 -/+ 2.8

type 1. type 2.

illumination

type 1.
clean:**d** 80% / **a** 20%

type 2.
dirty:**d** 10% / **a** 90%

daylight
artificial light

workplace total area

30+70+20 = 120

all rooms summed up [m²]

boolean indicators

true/positive
false/negative

rooms count

accodingly to number of “true” indications

4 and more

workshop to office ratio

o 20% / **w** 80%

office/studio or any not workshop area

workshop area

produced elements size

small, not significant for architectural consideradions

medium, small furniture sized sold in small amounts

big furniture size, for example tables, beds etc, closets.

big products that influence the space heavily, for example in terms of ceilling height[>10 m²]

stored elements size

small, not significant for architectural consideradions

medium, furniture sized but in small amounts - requiring a single rack [1-5 m²]

medium elements stored in big amounts, requiring few racks or rooms [5-10 m²]

big elements stored in big or small amounts, requiring few racks or rooms that influence the space heavily, for example in terms of ceilling height[>10 m²]

TABLE 2, p. 142.

how close to machines?

not connected to machines at all, or even someone else produces the design

the same “vicinity” but not connected to the design studio

connected to the design studio but in another room

design is made in the same room as the machines, no distincion between those two spaces

machine size

small, desktop sized (example - Ultimaker)

medium, desk sized

big sized, with big working areas requiring separate rooms or big spaces

industrial machines requiring vast spaces and supply chain

machine owned?

negative

positive

shared or leased

both tables:

value x — index in this box indicates to which profile is this user data assigned

value x — if the box is filled that means that this particular data is meeting the common trend in the group (or just being diferent even though it is the same profile - case of group 4). That shows what are the common trends for a certain profile and if a certain maker is following this trend or not.

TABLE 1.

	1. W 01 Peter Knoppers **Buttonius**	2. W 02 **Ben Hohmann** Sectie-C	3. W 03 Pieter Raat **Laserbeest**	4. W 04 Theo Wolters **Fabrique3d**	5. W 05 Neda Tozija **Transfodesign**
floor/levels number	1	2	3	4	2
floor height	1 -/+ 2.8	2 -/+ 6.0 -/+ 2.8	3 -/+ 3.5	4 -/+ 6.0 -/+ 4.0	2 -/+ n/d -/+ n/d
ilumination	**d** 45% / **a** 55%	clean:**d** 80% / **a** 20% dirty:**d** 10% / **a** 90%	**d** 65% / **a** 35%	office:**d** 50% / **a** 50% test:**d** 5% / **a** 95%	**d** 75% / **a** 25%
workplace area total [m²]	1 12	2 30+70+20 = 120	3 100+70 = 170	4 100+100 = 200	2 150+100+50=300
expand-ing?	1	2	3	4	2
rooms count	1	2	3	4	2
rooms types	1 1 - workshop/ design office/ storage	2 1 - clean workshop 2- design office 3 - dirty work-shop+storage	3 1 - workshop 2- cowork office 3 - storage 4 - air filter	4 1 - test workshop 2- **full** office 3 - rapid prototyping	2 1 - workshop 2- design office 3 - showroom 4 - cleaning, changing
office to workshop ratio	1 **o** 15% / **w** 80%	2 **o** 20% / **w** 80%	3 **o** 40% / **w** 60%	4 **o** 30% / **w** 70%	2 **o** 30% / **w** 70%
storage area [m²]	1 6	2 15	3 10	4 5	2 8
stored elements size	1	2	3	4	2
produced elements size	1	2	3	4	2

	6. W 06 Pieter Stoutjesdijk **TheNewMakers**	7. W 07 **Tiddo Bakker** Collaboration-O	8. W 08 Anna Ruiter **Tijelp Des./Maakbaar**	9. W 09 Daniel Marks **M edelsmen & design**	10. W 10 Kirsten Peerdeman **Atelier Indrukwekkend**
floor/levels number	4	2	1	3	3
floor height	-/+ 6.0 -/+ 3.0	-/+ 6.0 -/+ 3.0	-/+ 3.5	-/+ 2.5 -/+ 3.0	-/+ 4.0
daylight/ artificial	**d** 10% / **a** 90%	**d** 40% / **a** 60%	**d** 80% / **a** 20%	**d** 0% / **a** 100%	**d** 40% / **a** 60%
workplace area total [m²]	600+30+20=650	40+10+20=70	40+25+5=70	40+20 = 60	30+10+10 = 50
expand-ing?					
rooms count					
rooms types	1 - workshop 2- design office 3 - storage	1 - workshop 2- design office 3 - shared space	1 - workshop 2- storage 3 - shared space	1 - workshop 2- storage 3 - shop	1 - workshop 2- studio 3 - office 4 - store
office to workshop ratio	**o** 10% / **w** 90%	**o** 20% / **w** 80%	**o** 65% / **w** 35%	**o** 50% / **w** 50%	**o** 35% / **w** 65%
storage area [m²]	30	10	5	0	3
stored elements size					
produced elements size					

TABLE 2.

	1. W 01 Peter Knoppers **Buttonius**	2. W 02 **Ben Hohmann** Sectie-C	3. W 03 Pieter Raat **Laserbeest**	4. W 04 Theo Wolters **Fabrique3d**	5. W 05 Neda Tozija **Transfodesign**
additional facilities	[1] □	[2] □	[3] ■	[4] ■	[2] ■
technical appliances	[1] ■	[2] ■	[3] ■	[4] ■	[2] □
selling on place?	[1] □	[2] ■	[3] ■	[4] □	[2] □
crew size	[1] 1	[2] 1	[3] 5	[4] 10	[2] 3
number entrances for people	[1] 1	[2] 1	[3] 1	[4] 1	[2] 1
number entrances for suppl.	[1] 0	[2] 1	[3] 1	[4] 1	[2] 1
how close to machines?	[1] ■■ ■■	[2] ■■ □□	[3] ■■ ■□	[4] ■□ □□	[2] ■■ ■□
machine count	[1] ■■ ■□	[2] ■■ ■■	[3] ■■ ■■■	[4] ■■ ■■	[2] ■■ ■■
machine types	[1] ■■ ■□	[2] ■■ ■■	[3] ■□ □□	[4] ■■ ■■	[2] ■■ ■■
machine size	[1] ■□ □□	[2] ■■ ■■	[3] ■■ ■□	[4] ■■ ■■	[2] ■□ □□
machine shared?	[1] □	[2] ■	[3] □	[4] □	[2] □
machine owned?	[1] ■	[2] ■◩	[3] ■	[4] ■	[2] ■

	6. W 06 Pieter Stoutjesdijk **The New Makers**	7. W 07 **Tiddo Bakker** Collaboration-O	8. W 08 Anna Ruiter **Tijelp Des./Maakbaar**	9. W 09 Daniel Marks **M edelsmen & design**	10. W 10 Kirsten Peerdeman **Atelier Indrukwekkend**
additional facilities	[4] ■	[2] □	[1] □	[3] ■	[3] ■
technical appliances	[4] ■	[2] ■	[1] ■	[3] ■	[3] □
selling on place?	[4] □	[2] □	[1] □	[3] ■	[3] ■
crew size	[4] 8	[2] 1	[1] 1	[3] 4	[3] 2
number entrances for people	[4] 2	[2] 1	[1] 1	[3] 1	[3] 1
number entrances for suppl.	[4] 1	[2] 0	[1] 0	[3] 0	[3] 0
how close to machines?	[4] ■■ / ■□	[2] ■■ / ■□	[1] ■■ / □□	[3] ■■ / ■□	[3] ■■ / ■□
machine count	[4] ■■ / □□	[2] ■■ / ■■	[1] ■■ / ■■	[3] ■■ / ■■	[3] ■■ / ■■
machine types	[4] ■■ / □□	[2] ■■ / ■□	[1] ■■ / ■□	[3] ■■ / □□	[3] ■■ / □□
machine size	[4] ■■ / ■■	[2] ■■ / ■□	[1] ■■ / ■□	[3] ■■ / □□	[3] ■■ / ■□
machine shared?	[4] □	[2] ■	[1] ■	[3] □	[3] □
machine owned?	[4] ■	[2] ◩	[1] □	[3] ■	[3] ■

appendix 3.

Requirements for workshops of makers profiles

The first chart summarizes the maker profile and the second his workshop demands and requirements, in 3 different options - minimal, standard and maximal.

Hm_l

One Man Hobby

	P 01 Hm_l
activity description	VARIES
single/ how many?	one man company
collab.? single?	single
location	prv. apartment OR fablab
amount of machines	1-3
variety of machines	1-3
demand [m²]	~20
additional rooms	□
selling at place?	□
anybody visiting?	VARIES but not for pro reasons
pro/ hobby?	
how big are products?	■□ □□
how big is the storage?	■□ □□
how many custom.?	■□ □□
result: product/ service?	product

examples:
Buttonius
Tjielp Design
Full Bush Design

legend for icons: see p. 85 and 139

Profile 1

	minimal	standard	maximal	comments
area demand total [m²]	15	22	30	
rooms	1. design studio (general space access or all-in-one)	1. design studio 2. workshop with storage integrated	1. design studio 2. workshop 3. storage	users who do not make their designs themselves can order their designs for others to make or used shared machines
rooms area [m²]	1. design studio = 15	1. design studio = 10 2. workshop = 12	1. design studio = 10 2. workshop = 25 3. storage = 5	
additional facilities	-	meeting space	meeting space	
tech. appliances	sink	sink exhaust system	sink exhaust system	
machines amount	1	<3	<4	always depends on machine size, this number is an estimate
daylight contribution	**d** 50% / **a** 50%	**d** 70% / **a** 50%	**d** 70% / **a** 50%	estimations lowered because it was far from perfect in the visited workshops
additional rooms	-	-	-	
selling at place?	☐	☐	☐	
floor variation	☐	☐		
privacy levels	-	1. design studio = 1 2. workshop = 0	1. design studio = 1 2. workshop = 0 3. storage = 1	0 - lowest privacy level. Privacy level rises along with level number.
customizable facilities	-	workshop modular and reconfigurable	workshop modular and reconfigurable storage adaptable for workshop exp.	
workshop/off. ratio	**o** 50% / **w** 50%	**w** 70% / **o** 30%	**w** 80% / **o** 20%	
separate entrance for suppl.	☐	☐	☐	
var. name	**1OMH-1**	**1OMH-2**	**1OMH-3**	

legend for icons: see p. 85 and 139

Pc$_{II}$

One Man Professional in Collaboration

P 02 Pc$_{II}$	
activity description	VARIES
single/ how many?	one man company
collab.? single?	collaboration
location	shared space
amount of machines	3-6
variety of machines	3-6
demand [m^2]	~100
additional rooms	■
selling at place?	VARIES
anybody visiting?	□
pro/ hobby?	
how big are products?	VARIES
how big is the storage?	VARIES
how many custom.?	■■ □□
result: product/ service?	product

examples:
Sander Wassink
Joan Velve Raffecas
Ben Hohmann
Joost Gehem Designs
Kim Haagen Studio
Coradino Garofalo
Transfodesign*

*even though Tranfodesign is not a one man company, their activity and common characteristicts suit this profile the most. The fact that they work in 3 people team is the only diferrence from other companies in this group.

	minimal	standard	maximal	comments
area demand total [m²]	40	70	110	
rooms	1. design studio 2. own workshop + storage 3. general space access	1. design studio 2. own workshop + storage 3. general space access	1. design studio 2. dirty workshop + storage 3. clean workshop 4. showroom 5. general space	
rooms area [m²]	1. DS = 10 2. w + s = 20 3. GSA = 10	1. DS = 15 2. w + s = 40 3. GSA = 15	1. DS = 15 2. Dw + s = 40 3. CW = 30 4. SH = 5 5. GSA = 20	
addi-tional facilities	-	meeting space or showroom	- meeting space or showroom - distinction between clean and dirty work.	
tech. applianc-es	sink exhaust system	sink exhaust system compressor air filter	sink exhaust system compressor air filter	
ma-chines amount	>3	4<x<6	>6	always depends on ma-chine size, this number is an estimate
daylight contribu-tion	**r1: d** 60% / **a** 40% **r2,r3: d** 80% / **a** 20%	**r1: d** 60% / **a** 40% **r2,r3: d** 80% / **a** 20%	**r1,r4: d** 60% / **a** 40% **r2,r3,r5: d** 80% / **a** 20%	estimations lowered because it was far from perfect in the visited workshops
additional rooms or spaces	-	-	- showroom	
selling at place?	☐	☐	☐	
floor variation				
privacy levels	1. DS = 2 2. w + s = 1 3. GSA = 0	1. DS = 2 2. w + s = 1 3. GSA = 0	1. DS = 2 2. w + s = 1 3. SH = 1 4. GSA = 0	0 - lowest privacy level. Privacy level rises along with level number.
custom-izable facilities	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp.	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp.	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp.	
work-shop/off. ratio	**w** 70% / **o** 30%	**w** 70% / **o** 30%	**w** 70% / **o** 30%	
separate entrance for suppl.	☐	☐	■	
var. name	2OMPC-1	2OMPC-2	2OMPC-3	2OMPC-3 answers the need singalized by Transfodesign - collab. company which employs more than 1 person.

Sc_{III}

Small Company

	P 03 Sc_{III}
activity description	VARIES
single/ how many?	up to 8 employees
collab.? single?	single
location	own office
amount of machines	>5
variety of machines	1-2
demand [m^2]	~100
additional rooms	
selling at place?	
anybody visiting?	
pro/ hobby?	
how big are products?	
how big is the storage?	VARIES
how many custom.?	
result: product/ service?	VARIES

examples:
M-Edelsmeden + design
Atelier Indrukwekkend
Laserbeest

	minimal	standard	maximal	comments
area demand total [m²]	80	120	200	
rooms	1. workshop + storage 2. design studio 3. store	1. workshop + storage 2. design studio/co-work/w. for guests 3. meeting space 4. store	1. workshop + storage 2. design studio/co-work/w. for guests 3. meeting space 4. store	
rooms area [m²]	1. w + s = 60 2. DS = 10 3. S = 10	1. w + s = 60 2. DScw = 35 3. MS = 15 4. S = 10	1. w + s = 100 2. DScw = 70 3. MS = 20 4. S = 10	
additional facilities	showroom	meeting space + showroom	meeting space + showroom	
tech. appliances	sink exhaust system compressor air filter	sink exhaust system compressor air filter	sink exhaust system compressor air filter	
machines amount	>3	3<x<5	5<x<10	always depends on machine size, this number is an estimate
daylight contribution	**r2,r3: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	**r2,r3,r4: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	**r2,r3,r4: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	estimations lowered because it was far from perfect in the visited workshops
additional rooms or spaces	store	store co-work/ workshop for guests	store co-work/ workshop for guests	
selling at place?	■	■	■	
floor variation				
privacy levels	1. DS = 2 2. w + s = 1 3. S = 1	1. w + s = 1 2. DS = 2 3. MS = 1 4. S = 0	1. w + s = 1 2. DS = 2 3. MS = 1 4. S = 0	0 - lowest privacy level. Privacy level rises along with level number.
customizable facilities	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp.	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	
workshop/off. ratio	**w** 60% / **o** 40%	**w** 60% / **o** 40%	**w** 60% / **o** 40%	
separate entrance for suppl.	□	■	■	
var. name	3SC-1	3SC-2	3SC-3	

McIV

Medium Company of Makers

	P 04 McIV
activity description	VARIES
single/ how many?	more than 8 employees
collab.? single?	single
location	big hall
amount of machines	>2
variety of machines	1-2
demand [m^2]	>200
additional rooms	■
selling at place?	□
anybody visiting?	■
pro/ hobby?	
how big are products?	
how big is the storage?	VARIES
how many custom.?	
result: product/ service?	

examples:
The New Makers
WikihouseNL
Spidersigns

requirements for workshops
Profile 4 - parameters domain

	minimal	standard	maximal	comments
area demand total [m²]	200	250	300	
rooms	1. workshop 2. design studio 3. storage	1. workshop 2. design studio 3. storage 4. meeting space 5. manual workshop	1. workshop 2. design studio 3. storage 4. meeting space 5. manual workshop	main workshop space contains both clean and dirty sections
rooms area [m²]	1. W = 155 2. DS = 20 3. S = 25	1. w = 165 2. DS = 25 3. S = 30 4. MS = 15 5. MW = 15	1. w = 205 2. DS = 30 3. S = 35 4. MS = 15 5. MW = 15	
addi-tional facilities	showroom	1. meeting space 2. showroom 3. manual workshop	1. meeting space 2. showroom 3. manual workshop	
tech. applianc-es	sink exhaust system + compressor + air filter +	sink 2 x exhaust system + compressor + air filter +	sink 2 x exhaust system + compressor + air filter +	technical appliances need to be installed for both manual and digital workshops
ma-chines amount	<3	3<x<5	>8	always depends on ma-chine size, this number is an estimate
daylight contribu-tion	**r2,r3: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	**r2,r3,r4: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	**r2,r3,r4: d** 60% / **a** 40% **r1: d** 80% / **a** 20%	estimations lowered because it was far from perfect in the visited workshops
additional rooms or spaces	store	for tech appli-ances	for tech appli-ances	
selling at place?	☐	☐	☐	
floor variation				
privacy levels	1. W = 1 2. DS = 2 3. S = 1	1. w = 1 2. DS = 2 3. S = 1 4. MS = 0 5. MW = 1	1. w = 1 2. DS = 2 3. S = 1 4. MS = 0 5. MW = 1	0 - lowest privacy level. Privacy level rises along with level number.
custom-izable facilities	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	
work-shop/off. ratio	**w** 80% / **o** 20%	**w** 80% / **o** 20%	**w** 80% / **o** 20%	
separate entrance for suppl.	■	■	■	
var. name	1OMPC-1	1OMPC-2	1OMPC-3	

Pd_v

Medium Company of Product Developers

common characteristics:

- company specialized in development of products and industrial design
- a lot of orders - 10 weekly
- >8 employees
- company works on multiple projects simultaneously
- big area demand for workspace and advances technical appliances needed
- small number of machine types but very advanced ones, industrial top notch
- products are big sized and affect working space, need special logistics or vehicles to be moved

not common characteristics:

- services and designed products
- production place

examples:
Fabrique3d
SuperLofts

Because of significant diferrences of this profile in the needs (in general, product developers need more office space than a workshop) the author decicded not to take them in account as the potencial user of the system.

	P 05 Pd_v
activity description	VARIES
single/ how many?	more than 8 employees
collab.? single?	single
location	office space
amount of machines	>4
variety of machines	>4
demand [m²]	>200
additional rooms	■
selling at place?	□
anybody visiting?	■
pro/ hobby?	
how big are products?	
how big is the storage?	VARIES
how many custom.?	
result: product/ service?	

	minimal	standard	maximal	comments
area demand total [m^2]	150	200	250	
rooms	1. full design office 2. rapid prototyping 3. workshop	1. full design office 2. rapid prototyping 3. workshop	1. full design office 2. rapid prototyping 3. workshop	- main workshop space contains both clean and dirty sections - workshop doesn't have to be well connected with office
rooms area [m^2]	1. FDO = 80 2. RP = 10 3. W = 60	1. FDO = 110 2. RP = 15 3. W = 75	1. FDO = 130 2. RP = 15 3. W = 115	
addi-tional facilities	office facilities	office facilities	office facilities	
tech. applianc-es	sink exhaust system + compressor + air filter +	sink 2 x exhaust system + compressor + air filter +	sink 2 x exhaust system + compressor + air filter +	
ma-chines amount	<3	3<x<5	>8	always depends on ma-chine size, this number is an estimate
daylight contribu-tion	**r1: d** 60% / **a** 40% **r1,r2: d** 80% / **a** 20%	**r1: d** 60% / **a** 40% **r1,r2: d** 80% / **a** 20%	**r1: d** 60% / **a** 40% **r1,r2: d** 80% / **a** 20%	estimations lowered because it was far from perfect in the visited workshops
additional rooms or spaces	office fac.	office fac.	office fac.	
selling at place?	☐	☐	☐	
floor variation				
privacy levels	1. FDO = 1 2. RP = 2 3. W = 3	1. FDO = 1 2. RP = 2 3. W = 3	1. FDO = 1 2. RP = 2 3. W = 3	0 - lowest privacy level. Privacy level rises along with level number.
custom-izable facilities	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	■ workshop modular and reconfigurable ■ storage adaptable for workshop exp. ■ workshop extension possible	
work-shop/off. ratio	**o** 60% / **w** 40%	**o** 60% / **w** 40%	**o** 60% / **w** 40%	
separate entrance for suppl.	■	■	■	
var. name	**5MCPD-1**	**5MCPD-2**	**5MCPD-3**	

appendix 4.

Feed #1 to #2 - requirements for customization and evaluation

From the first part of the research there can be defined requirements for customization method as follows:

1 modular friendlyness;

2 open source;

3 level of user influence;

4 efficiency of combinations;

5 design freedom;

6 depth of customization;

7 potential for reconfiguration.

These requirements are not equal, therefore an evaluation is following on the next page. Aim of it is a weight definition for each of the requirements.

	1	2	3	4	5	6	7	(s)CORE	(w)EIGHT
1 modular friendlyness;		1	1	1	1	1	0	6	**III**
2 open source;	0		1	1	1	1	1	5	**III**
3 level of user influence;	0	0		1	1	1	0	3	**II**
4 efficiency of combinations;	0	0	0		0	1	0	1	**I**
5 design freedom;	0	0	0	1		0	0	1	**I**
6 depth of customization;	0	0	0	0	1		0	3	**II**
7 potential for reconfiguration.	1	1	1	1	1	1		6	**III**

weights:
w=1 *if* $1 \leq s \leq 2$
w=2 *if* $2 < s < 5$
w=3 *if* $5 \leq s \leq 7$

appendix 5.

Feed #1 (and #2) to #3 - requirements for digital fabrication and evaluation

From the first part of the research there can be defined require ments for digital fabrication method as follows:

1 reconfiguration potential

2 modular friendly

3 customizable friendly

4 large spans durability

5 multifloor durabiliy

6 rooflights possible

7 easy to produce

8 produced by common digital fabrication machines

9 easy assemble

10 easy dissasemble

11 material price

12 machine price

13 structure durability

14 material weight

15 environmental impact

16 material waste

17 process time

18 assembly time

19 amount of elements

20 elements variation

21 elements size

22 cognitive ergonomics

23 additional tools needed

24 additional components needed

25 toxicity

26 additional efforts

27 recyclable

28 reusable

29 additional assembly costs

30 additional physical characteristics

31 ability to perform as an integral part of the building

These requirements are not equal, therefore an evaluation is following on the next page. Aim of it is a weight definition for each of the requirements which will be performed on the following page.

requirements for digital fabrication

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	(s)CORE	(w)EIGHT
1		1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	24	III
2	0		0	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	21	III
3	0	1		0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	22	III
4	0	1	0		0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	23	III
5	0	1	1	1		1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	26	III
6	0	0	0	0	0		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	I
7	1	0	1	0	0	1		0	1	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	20	II
8	0	1	0	0	0	1	1		1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	24	III
9	0	0	0	0	0	1	1	0		1	1	1	0	0	1	1	1	0	1	0	0	0	0	1	0	0	1	1	1	0	0	13	II
10	0	0	0	0	0	1	0	0	0		1	1	0	0	1	1	1	1	0	0	0	0	1	1	0	0	1	1	1	1	0	11	II
11	0	0	0	0	0	1	0	0	0	0		1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	7	I
12	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I
13	0	0	0	1	1	0	0	0	1	1	1	1		1	0	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	0	18	II
14	1	1	0	0	0	1	1	1	1	1	1	1	0		1	1	1	1	1	1	0	1	1	1	0	1	0	0	1	0	0	21	III
15	0	0	0	0	0	1	0	0	0	0	1	1	1	0		1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	0	15	II
16	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0		1	1	1	1	0	0	1	1	0	1	0	0	1	1	0	13	II
17	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0		1	0	1	0	0	0	0	0	0	0	0	1	0	0	7	I
18	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0		1	0	0	0	1	0	0	0	0	0	1	0	0	7	I
19	0	0	0	0	0	1	0	0	0	1	1	1	1	0	0	0	1	0		1	0	0	0	1	0	1	0	0	1	0	0	9	I
20	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	0	1		0	0	1	1	0	1	0	0	0	0	0	8	III
21	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1		1	1	1	0	1	0	0	1	1	1	26	III
22	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	1	1	1	1	1	0		1	1	0	1	0	0	0	0	0	12	II
23	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0	1	0	1	0	0	0		1	0	1	0	0	1	0	0	9	I
24	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0		0	0	0	0	1	0	0	5	I
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	31	III
26	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0		0	0	1	0	0	8	I
27	0	0	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1		1	1	1	0	21	III
28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1		1	1	1	18	II
29	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0		0	0	5	I
30	0	0	0	0	0	1	0	0	1	0	1	1	0	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1		0	12	II
31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1		29	III

weights:
w=1 *if* $1 \leq s \leq 10$
w=2 *if* $11 < s < 20$
w=3 *if* $21 \leq s \leq 31$

appendix 6.

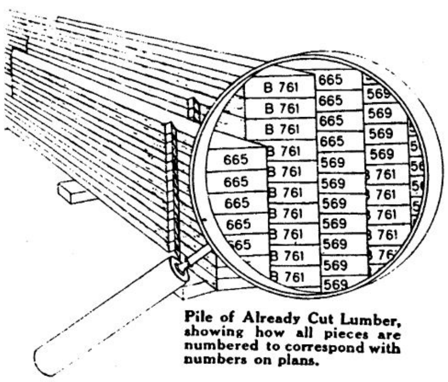
Mass Customized Design Systems

Mass Customization Design Systems for building industry

Systems for mass customization were made mostly for housing however this paragraph is dedicated to systems and methods and will investigate them in a clearly utilitarian way. The following examples present the selection of different systems applied to customize housing accordingly to user needs.

1. Sears Prefabricated Houses

Sears, Roebuck and Company is one of the first agents in the history of mass customization. According to Cook and Friedman (2001) company, sold between 70,000 and 100,000 (mostly) single detached houses between 1908 and 1940. Sears where indeed ahead of their times - their business was basing on shipped pre-cut sets of parts, which assembled together made a complete house, which form, size etc. was picked by the client from a mail ordered catalogue.



Pre-cut lumber was labeled - notice the similarities of todays digitally fabricated parts with tags

The package was complete, down to the nails and bored holes for screws. Building paper, paint and varnishes, lumber, lath, shingles, roofing and windows were included. A complete house materials could fit into two boxcars and be easily transported on site, where the house could be completed in 1 day by two by not qualified people (Simplex Cottage) or in the case of more complicated ones - it saved tremendous time, but had to be assebled by workers.

While catalogue houses and prefab usually is misconcepted as low quality and temporary or substandard Sears managed to succeed and provide more than satisfactory result. All materials that were used were of the highest quality while houses provided highest standards in terms of building physics. As for the temporariness that was a wrong impression, as many of those houses exist today.

Design of the houses was unique - there can't be defined a typology of the Sears house as all were customized for clients in terms of both spatial design and finishes. Each new house required some extra drafting work accordingly to customers liking. Clients also could bring their own designs which would be then adapted to the system's technology. That resulted in endless variety of shapes and sizes of the houses, suitable for those from the cities as well for those from more rural areas.

2. Shape Grammars

A more contemporary case study is presented by Jose P. Duarte (2005) who adapted the system of shape grammars, which allows for an interactive computer program to generate housing solutions along with rapid prototyping files, as well as virtual reality techniques for visualisation.

Duarte presents his concept basing on Alvaro Siza's houses at Malagueira. First houses of this development were built in 1978. Designer devised a pattern which allowed for generation of different houses, what resulted in 35 layouts designed - from one bedroom to five bedroom houses, what was supposed to satisfy clients needs for custom and unique housing. However, Duarte notices limitations which his system was supposed to overcome - there was no explicit set of rules firstly, secondly, limited ways of presentation of the many generated variants instead of informing clients confused them. Thirdly, in eyes of Duarte, the potential of customization of housing was not fully utilized.

Duarte's system using shape grammars provides the following positive aspects:

- technical aparatus provided by shape grammars allows for explicit rules
- shape grammars contribute for a complete system generating houses for Malagueira development
- computer generated content is produced more efficiently

The program was planned to be accessible online, and via an interview was supposed to collect users data and their requirements for housing. The program will generate a design brief which adjusts users needs to legal regulations. If the user will accept the brief (if not, the initial requirements can be modified) the program will generate a solution that satisfies the users stated requirements This stage can also be assesed and improved by the user and another iteration will be provided. Once a solution is approved the program will deliver files to a manufacturers, the parts of the house will be produced and deliver to the site where the house is finally assembled.

Shape grammars were first introduced by Geoge Stiny (1980) and mean a system of production which generates geometrical shapes both in 2 dimensions and 3. A shape grammar consist of shape rules and a generation engine which first selects the rule and then processes it. Academic world employed SG widely however it never become popular in CAD or any professional applications.

3. The Panelized Kit Approach

The Rocio Romero LLC company provides a customizable housing system which allows a consumer to select and combine the house elements which they like in the domain of constraints of the options available, according to Anderson (2009). This product is called FlatPak House and is described as a modern kit home which is affordable, easy to build and customizable. However comparing to other systems, this provides quite limited options. The company provides only kit set for the outer layers while some structure elements, installations, foundations and finishes must be installed and brought by the contractor. Maybe this system is not as complete as the historical Sears approach, but thanks to that the FlatPak House designers are able to focus on a thoroughly detailed yet simple and easy to erect basic building system. That allows for lowering the cost and time of building what is sometimes the most important factor for a middle-class buyer.

4. The Component Approach

This system employs off-the-shelf elemets and uses them to compose modular, custom building parts and furniture which together contribute to variety of configurations of spaces. Example of such approach - Kieran's Timberlake Cellophane House - will be described in the next section of this chapter.

5. Participatory Design

P. D. first defined by Sanoff (1990) is the act of involving the customer into the design process and can proceeded differently: in a co-located way or a dislocated.
The first one is a typical situation when the architect and customer is meeting in person to discuss the design and place order.
In recent time however, the second method is gaining momentum - dislocated participatory design, which is a sort of multiple choice system, presented to buyers. The client has multiple, limited options for each space in the house (Hofman et al., 2006). Similar to Duarte's concept, this method takes a form of a computer app that allows to modify the design accordingly to needs. However, because of the combinatorial possibilities that the design offers, it should be provided as a parametric system - the designer will never be able to create all the endless possibilities. Examples of this approach will be presented in the following section of this paper.

6. User Driven Design/IKEA

This system is highly involving the client into the design process and depending on their preference. Ikea is an example of a company, which incorporates this system and perfectly overcomes the issue mentioned in the previous one. Ikea offers modular, serial produced items which assembled by clients into systems (for example storage system inside a closet) provide wide spectrum of customizability, and is still mass produced. In architecture this system is employed by Heijmans (2011) and will be described in the following section.

7. ABC Customization Design System + Kingspan building system

According to Duarte (2009) and Słyk and Kwieciński (2014) Manuel Gausa created the ABC design system. Name of the system derrives from Armario, Bano and Cocina (closet, bathroom and kitchen in spanish) and places these in a column-free floor area according to a predefined set of rules which allows for multiple generations of different plans. This system uses parametric logic what makes it much easier to handle and control, than for example shape grammars (Stiny, 1980) and is more flexible thanks to algorithmic constraints control.

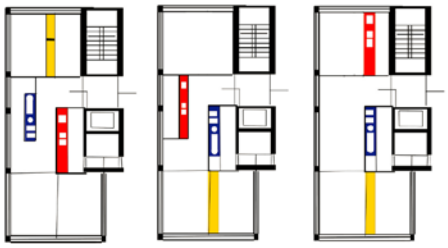


Fig. 1 - samples of floor plans generated with the ABC system, colored areas represent closet (armario), bathroom (bano) and kitchen (cocina). (Duarte 2009)

The ABC system had a chance for realisation when Gausa was asked for collaboration with a Irish company Kingspan producing a prefabricated building system using cold formed steel structure combined with a modular envelope with finish elements. Even though it has difficulties in becoming popular in the building industry because high level of complication it presents high flexibility and versatility. This system has constraints which the structure can hold - up to 6 storeys of height while the grid has a maximum of 16 x 4.5 x 3 m (lenght x width x height).

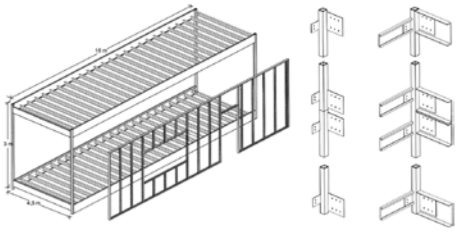


Fig.2 Kinspan system module and joinery (Duarte, 2009)

The design system and the building one completed each other and had similar constraints. Compilation method aimed to stretch the available possilibilities and potential of both systems what resulted in wider numbers of configurations. After the compilation, the range of dwellings spreaded from studios to 4 bedroom apartments, areas of which covered domain of 50 to 150 m^2 while the building height started at two floors up to six.

appendix 7.

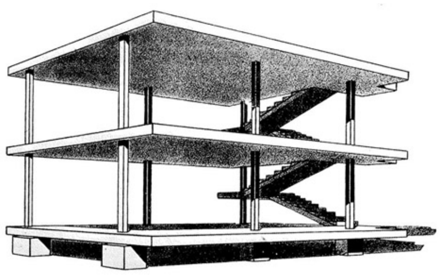
Mass customization in buildings

Mass Customizable Building Systems and Reconfigurable Offices Case Studies

Mass Customization is mostly practised in housing architecture, as this domain requires most personal approach to design. When it comes to workplaces, although this trend started a long time ago with the birth of the well known concept of the open space in the 50s it was not much more developed. Open space proved to deliver many disadvantages what resulted in diversyfying workplaces, and shifting towards landscaping the open space to provide diversified rooms and areas. Also, the possibility of reconfiguration provided by the open plan was used only when a new company moved into a certain building, not while it was already renting the place - corporate business companies usually do not recunfigure their workplaces, but stay with one setup.

Historical:

1. Dom-ino House



A very well known design for mass customizable building comes from Le Corbusier. Even though it was not realized, between 1914 and 1915 the ingenious architect envisioned a system consisting of minimal amount of sleek columns and slabs connected vertically with staircases, allowing for full customizability of the floor. Rather a framework than a complete desing, Dom-ino was planned to be mass-produced but still delivered a high degree of flexibility as floor plans, technical apliances and wall finishes were totally up to the client.

2. Rietveld-Schroederhaus

In 1924 dutch architect Gerrit Rietveld together with his client Truus Schroeder designed a house which significantly contributed to the discussion about customizability and reconfiguration. All inner walls are not fixed and can move

along their main axes. Because of that, the dwellers are capable of redefining and reconfigurating their floor plan whenever they need. As Niemeyer notices (2011) it is an example of adaptive customization, as the product is standardized but allows for modifications accordingly to user needs.

3. Habraken's system

In 1972 John Habraken published his book "Supports, an alternative to mass housing" (Habraken, 1972) where he describes his unique concept for customizable mass dwellings. Habraken stated that mass production distances client from influence on architecture and proposed an unique systems consisting of supporst and infills. The latter, are spaces used and configurated by users, are personal and customizable while supports sphere is all that is constant and unified in each building - structure, technical installations etc. That resulted in rather small amount of support versions but highly flexible to accomodate any infills, as well as a wide variety of infill possibilities.

Contemporary:

1. SuperLofts

Superlofts is a framework system for customizable apartments created by Marc Koehler Architects (superlofts.co, 2016; marckoehler.nl, 2016). All apartments are double floor and can be planned in whatever way the client will desire, with assist of the architects from MKA or on their own. What is more, the client influences also with the location and shape of the entire building. The main principal that makes Superlofts unique is that the client is the central agent of the process, instead of the developer. That results in larger spaces, higher quality materials and better cratsmanship as well as higher energy efficiency of the buildings. Unlike in commercialy developed houses, communal spaces can be implemented without rising investment cost, thanks to the flexible design. Thanks to this sort of bottom-up approach any of the houses is a vertical community, or village, according to the author - Mark Koehler. That is answering the varied needs of modern society which is diverse and has unique needs.

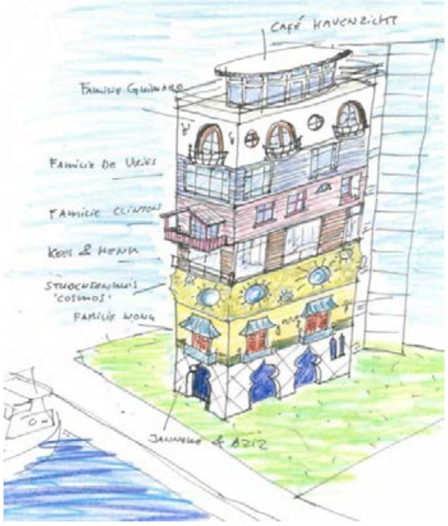
2. Housing Configurators

Dutch company HOYT offers a web application which according to their "Personal Housing Concept" allows to configurate a house online. Each configuratior is dedicated to a specific project, which can span from single houses to whole neighbourhoods.

The configurator allows the client for a full control over his ownfuture housing. They can specify their needs once and reconfigure them all over again how many time they want. Thanks to the user friendly and clear interface the configuration is easy but it is often very limited. The user has no real influence on the floor plans and areas of rooms or their relations.
(hoyt.nl, 2016)

3. De 7 Hemels (2002)

Hoyt (formerly BBVH), a dutch company, offers configuration of their apartments which maximizes the clients involvement in the design process. As the authors state, it is the first time i nthe Netherlands when there is a possibility to entirely affect your apartment in a stacked block of flats and be able to further modify it and reconfigure.



The buiding has a steel frame and technical shafts etc that remain unchangable and unified for all floors in the initial phase of the building life, however the piping and sewage can be altered later. What results from that is the complete freedom of each floor and a real open plan available for clients. (hoyt.nl, 2016)

4. WikiHouse (2012)

WikiHouse is an open source platform which is the reflection of such internet giants as Youtube, AirBnB or Wikipedia - informs the website (wikihouse.cc, 2016). Authors - Alastair Parvin and Nick Ierodiaconou - say, that with the current industrial revolution all that is made locally, with use of digital tools

changes the way we deisgn our homes. The WikiHouse system enables to locally and solely build a house without any specialized contractor and offers a wide field of customization. First reason for this statement is the opennes of the system - user can adapt it to their needs and modify the house in whatever way they want. Thanks to parametric models, open data instantly calculate cost, time, performance and impact and to produce manufacturing information. The system provides four predefined options of houses - Studio, Longhouse, Townhouse and Microhouse. (wikihouse.cc, 2016)

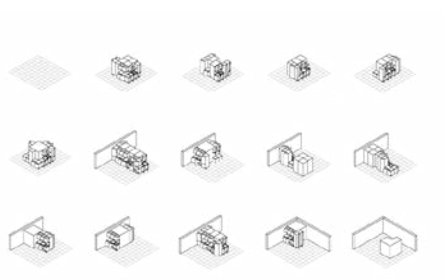
5. Hermit House

Hermit House system offers numerous affordable building scenarios from prefabricated DIY construction kits to open source building manuals. Added to that a mass customization design application will be available on the company's website.

Thanks to a unique building method used by Hermit House along with parametric software it is possible to quickly adapt house design in many varieties and options. All homes come to the client as a easy to build package, which can be erected by the user in two days. (hermithouses.nl, designboom.com, 2013)

6. The New Makers

The New Makers is a company that uses one technology, one material and the same approach on different fields.



Comfort Cabin

This branch offers a solution to municipalities, housing associations, developers and other stakeholders to provide a fast, efficient and demountable installation package.
First stage of the proccess considers a visit on location, where materials, configuration and the overal look is defined.
Then, a draft proposal is prepared basing on requirements determining the conditions for the delivery and installation.
Once approved, production can begin. Within no time, the tailored, reconfigurable cabins appear on location and become functional.

7. Tailorhousing/Wenswonen

This option, provided by the company Heijmanns offers the client customizability via an online browser app. The client has choices on different levels - first, what kind of house they will want to look for. Then further customization takes place, in predefined, but very general frames like orientation, width and height of the house. First the client choses from predefined options of extensions, facace options and immediately see the effects to the street. Then, the client can influences the interior and garden, again from predefined options.

7. Cellophane House

According to Anderson (2009) and projects author website (www.kierantimberlake.com, 2016) the system represents a bottom-up approach which comes from the nature of the system assebly - it provides many varieties of final result. As the website informs, it can be made of different materials that will suit many needs, tastes and budgets. Its flexibility allows to adapt to different sites and climate conditions as well as different plots as the floor plan is reconfigurable. Although the construction system is not yet that heavily tested, the contractors might charge higher prices for their work thus the system becomes less affordable financially.

7. Minima Moralia

Minima Moralia by Tomaso Boano and Jonas Prišmontas is a compact, pop-up design studios for designers, sculptors, painters, musicians and other creatives.
Minima Moralia anwers the need for affordable workspaces for creatives in London, which today is very expensive in terms of rentin a workspace, from a small creative point of view.
Each of the workspace boxes is a temporary workplace for an artist.These units present a potential of creating new urban typologies and creative communities utilizing unused public or private spaces of London.
Minima Moralia appears as a minimal, translucent structure. Steel frame is cladded with plexiglass walls and roof. Some of the walls have openings allowing outside to penetrate even more than just because of the see-through character of walls. Moreover, it sets up a spatial dialogue with surroundgins. Modular steel frame creates an empty grid with multiple potential for internal configurations and customization. Shelves, desks, artificial lights and curtains can be provided, to meet the user's needs. (minimamoralia.co.uk, 2016)


Fig.1 Minima Moralia opens up for its surroundings (minimamoralia.co.uk, 2016)

8. Pop Up Box

The Pop Up Box by DITTEL ARCHITEKTEN GMBH is a stand alone retail space finding first use in the mall of the Gerber shopping centre in Stuttgart. Fully convertible, it offers retailers and exhibitors a customizable presentation area. It's a system that is self-contained and out-of-the-box. All required facilities for commerce united under an umbrella of technology and design come in one box.
The user of the system can open the Pop Up Box and move three of the four individual elements anywhere in the room and in order to create their own sales with the capacity of 20 to 30 m^2, which is accessible for visitors with disabilities. Inside of the structure contains a customizable system for exhibiting, selling and testing goods and thanks to the recofigurablr setup the retail space becomes extremely flexible. (di-a.de, 2016) ■

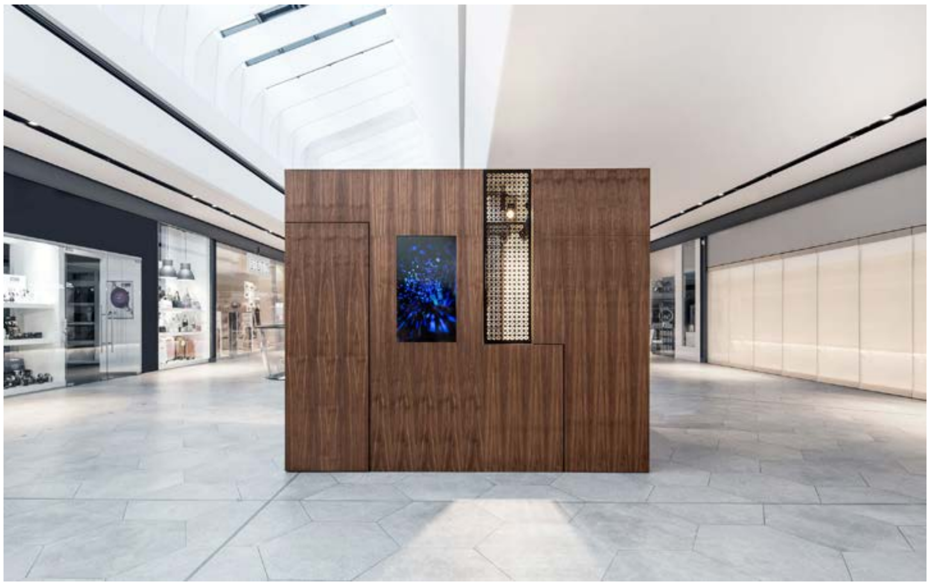


Fig. 2 Pop Up Box when closed (di-a.de, 2016)


Fig. 3 Pop Up Box when open (di-a.de, 2016)

appendix 8.

Feed #2 to #1 - customization and the client

The second chapter of this paper takes the data and conclusions from the first part and passes it through the theory and practice of customization in order to understand how can the needs of makers be fullfilled by mass customization. Knowlegde obtained from the second part of the research allows for better understanding of the whole reconfigurable and personalizable part of the research. Apart from that, all the knowlegde which is not beneficial for this research directly can be also used in any design phase inspired by or based on it.

These are the ingrediuents of the feedback loop which empower the first part of this research:

Redefinition of makers profiles and the target customer of this research.

Better understanding how coaching and curating of the creative environment can be performed;

Better understanding of the relations occuring while exchanging gear and elements of the workshop and all benefits from the constant interactions with other designers; awareness of the relations that can be born between users of the workshop;

Better understanding of the treatments of clients and comparison to other approaches towards the customer;

Better overview of what could be offered to the customer and how a workshop can be customized.

appendix 9.

Scoring of traditional methods in comparison to digital fabrication

Standard concrete column - slab system

(Soutsos, 2011)

product material	concrete
supporting material	betonplex etc. for moulds
finishing needed?	no
optional finishing	plastering system facades any traditional wall finishes
max. el. size [mm]	depends on tech - standard span 7200mm
material components	- cement - microsilica - aggregate - water - placticizer - steel rebars
common application	Construction industry
additional effort	vibration

1 reconfiguration potential (III)

2 modular friendly (III)

3 customizable friendly (III)

4 ability to perform as an integral part of the building (III)

5 easy assemble (II)

6 easy dissasemble (II)

7 structure durability (II)

8 rooflights possible (I)

9 large span durability (III)

10 multifloor durabiliy (III)

11 material weight (III)

12 toxicity (III)

13 recyclable (III)

14 reusable (II)

15 additional physical characteristics(II)

16 environmental impact (II)

17 material price (I)

18 produced by common digital fabrication machines (III)

19 elements size (III)

20 easy to produce (II)

21 material waste (II)

22 cognitive ergonomics (II)

23 machine price (I)

24 process time (I)

25 assembly time (I)

26 amount of elements (I)

27 elements variation (I)

28 additional tools needed (I)

29 additional components needed (I)

30 additional efforts (I)

31 additional assembly costs (I)

final score

2.14/4

Standard steel frame structure

(da Silva et al., 2013)

product material	steel
sup-porting material	-
finishing needed?	yes, fireproofing
optional finishing	painting
max. el. size [mm]	-
joints	welding or mechanical joints
common applica-tion	Construction industry

1 reconfiguration potential (III)	■■□□
2 modular friendly (III)	■■■■
3 customizable friendly (III)	■■■□
4 ability to perform as an integral part of the building (III)	■■■■
5 easy assemble (II)	■□□□
6 easy dissasemble (II)	■■□□
7 structure durability (II)	■■■■
8 rooflights possible (I)	■■■■
9 large span durability (III)	■■■■
10 multifloor durabiliy (III)	■■■■
11 material weight (III)	■□□□
12 toxicity (III)	■■■■
13 recyclable (III)	■■■□
14 reusable (II)	■■■■
15 additional physical characteris-tics(II)	■□□□
16 environmental impact (II)	■■□□
17 material price (I)	■□□□
18 produced by common digital fabrication machines (III)	□□□□
19 elements size (III)	□□□□
20 easy to produce (II)	■□□□
21 material waste (II)	□□□□
22 cognitive ergonomics (II)	■■■□
23 machine price (I)	■■□□
24 process time (I)	■■■□
25 assembly time (I)	■■■■
26 amount of elements (I)	■■■□
27 elements variation (I)	■■■□
28 additional tools needed (I)	■■■□
29 additional components needed (I)	■■■□
30 additional efforts (I)	■■□□
31 additional assembly costs (I)	■■■□

2.48/4 final score

appendix 10.

Feed #3 to #1 - client limitations

The third chapter of this paper presents various approaches to digital fabrication. Thanks to that it is possible to understand who is able to use digital fabrication and to what extent can it be used freely and effectively in a evolving, creative environment.

These are the ingredients of the feedback loop which empower the first part of this research:

Redefinition of makers profiles and the target customer of this research.

What kind of users are applicable to use a reconfigurable system and use digital fabrication both for their work and defining workspace;

How experienced should be the customer, or how easy should be the chosen fabrication method;

Better view on the organization of the workspace and amount of machines needed for operation - both for working and making elements for the workspace; also the amount of people needed for the whole unit of a workspace;

appendix 11.

Feed #3 to #2 - technology and customizability

The third chapter of this paper presents various approaches to digital fabrication. Thanks to that it is possible to understand what is the spectrum of customization considering the best suiting technology.

These are the ingredients of the feedback loop which empower the first part of this research:

What are the limitations of modularity and customizability in certain digital fabrication methods;

How deep can be the customization level even in case of the most promising technologies;

What detailed technical customization approaches can be implemented depending on technology;

How deep can be the customization influence and what exactly can be customized using a particular digital fabrication method - only the primary structure, part of it, or maybe furniture.

aec

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