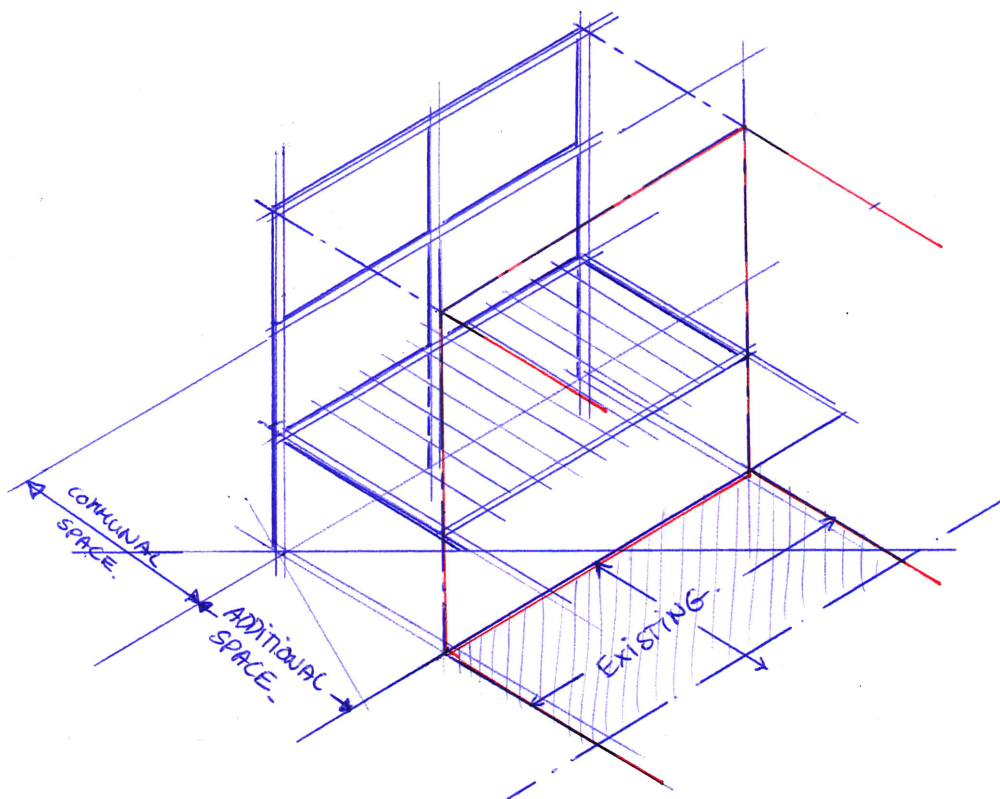
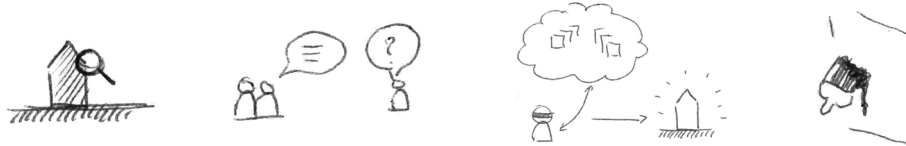


Customisability for a better sense of home

Enabling participation in dwellings

June 2016, Jelle Grunstra (4163834)
Research paper, Architectural Engineering



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Graduation studio: Architectural Engineering

Research paper

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Title

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Abstract

Dealing with the existing stock is the challenge for the coming decades in the Netherlands. At the same time, user demands and regulations increase and should be met. Users want more influence in their surroundings. By enabling them to participate in their dwelling, they have a greater sense of place, which diminishes a negative social impact. Moreover, they will stay longer at the same place and social cohesion is enhanced.

User participation has been tried many times in history, all failing due to different reasons. These examples are analysed to prevent failure in this graduation project. One most successful theory is discussed extensively, but is not the final solution. Discussed problems are overcome with technology that is present today and can enhance the paradigm. This leads to an enhanced framework, called UPHome.

Hypothesis

Reflecting on architectural history and rising modern technology, it is now possible to implement the user in the building process.

Research questions

How has the user participated in the past, and how should this be done in the present day?

1. Why should users participate in the creation of their dwellings?
2. How has the user participated during the creation process in the past?
3. What product manufacturing paradigms are there and how do they work and differ from each other?
4. How can these paradigms be translated to architecture and how does this differ from what has been done before?

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000 BACKGROUND

In order to understand choices made in this research paper, a background will be provided. This focusses on the problems in the built environment and personalisation trends that arise today, history and reasons for user participation in the creation of their dwelling and the context in Amsterdam, namely the Nemavo-Airey building blocks.

000.1 Problem statement

Dealing with the existing stock is the challenge for the coming decades in the Netherlands. At the same time, user demands and regulations increase and should be met.

Replacing the existing stock does not happen quickly as buildings have some market value and demolition results in a lot of material waste¹. Moreover, the impact on current home owners is large as they have to move away from the neighbourhood they know and have lived in for a long time². As a result, demolishing a building is at the bottom of the priority list in the built environment. Refurbishment of the existing stock therefore becomes a priority.

On the other hand we see the changing role of the consumer in today's society, moving from a consumer to a *prosumer*, with personalised products³. The introduction of direct digital manufacturing⁴ makes it possible for consumer to customise the products they buy or even be produced for them specifically like the 3D printed bra from Mesh Lingerie⁵.

The demand for customisation has also entered the housing market and seems to be taking some ground^{6,7,8,9,10}. iQwoning, part of Ballast Nedam, offers a modular housing concept which speeds up the construction process and cuts cost down. Future owners can choose from several dwelling types in order to possibly fulfil their needs as best. The downside from all these concepts is that they focus on new built dwellings instead of existing ones, with the 'Klushuizen' in Rotterdam as the only exception, but here users need to do all the adaptations themselves or need to hire someone to do it for them.

One target group that most certainly needs a dwelling suited to their needs are the asylum seekers. They have been granted a longer stay and are in need of a dwelling, of which not many are available¹¹. By making a building easily adaptable, it becomes possible to let the dwelling better suit the home owner's needs which are different from our Western culture¹².

000.2 History of participation

Until midway through the twentieth century, it was common for residents to build their homes in an individual or collective manner. With the emergence of the industrial age, forms of collective private housing began to appear in rapid growing cities¹³. Poor hygiene and social problems, and the resulting 1901 Housing Act, made that workers needed to get organised to set up collective private commissioning.

¹ Power (2008, pp. 4489–4490)

² Due to increasing mobility our society changes towards a network-oriented one meaning people are less likely to live at one place for a long time. If this a good or bad thing is discussed later.

³ Chen et al. (2015, p. 618)

⁴ Chen et al. (2015, p. 618; Sogeti VINT (2014)

⁵ Twillert (2015)

⁶ Discussion between young starters about preferred housing needs. Ouwerkerk (2014)

⁷ 'Dozens of housing concepts to better suit user needs'. TBI (2014)

⁸ Modular housing concept, prefab built. iQWoning (2012)

⁹ 'Klushuis', letting owners do much more on their own. CoBouw (2009)

¹⁰ Zijlstra and Stolwijk (2011, p. 13)

¹¹ Bouwformatie (2016)

¹² Koff (2016)

¹³ Boelens and Visser (2011, pp. 104–105)

After the Second World War, the government of the Netherlands took a leading role in reconstructing the built environment as well as reacting to the rising housing need¹⁴. Mass housing was needed to supply everyone with a decent dwelling for an affordable price. Unfortunately this meant dulling down the design and leaving out the user. Eventually, resistance against this arose in the 1970s¹⁵.

Still, today it is quite normal for the consumer to take a passive role and find a home to what is available on the market or what corporations allocate¹⁶.

000.3 Research surrounding participation

While our network-based society makes us more mobile it also creates individualisation and social fragmentation. This leads to a greater need of people to link with their surroundings as well as taking actions into their own hands and want to be more involved in aspects that influence their lives¹⁷. People constructing a house or houses in a collective manner would resemble a more plural, self-organised and bottom-up, multifaceted society¹⁸.

Research¹⁹, investigating (collective) private commissioning, first of all showed that people within a neighbourhood have a stronger social cohesion among them due to group forming during the project. A side note is that this could lead to a 'different' or 'gated' community. Second, there is a low rate at which people move away. Third, residents were most interested in the design and layout of their dwellings, after which came the surrounding area followed by architecture & façade. Architectural quality and possibility to sell their home was not really important. Fourth, this type of construction is only suitable for a small group of people, but in the right circumstances can enhance the quality of the housing stock and wider living environment. 'Moreover it could indeed better meet changing and increasingly specific and wide-ranging consumer preferences in a more and more plural society, when left to itself.'²⁰

Meeting these preferences has also been achieved with 'Klushuizen' which originated in Rotterdam. These houses can be bought cheap, but need to be heavily renovated²¹. For rental apartments, users are given a budget to refurbish the dwelling to their own needs²². Owners can do most work themselves to save money, which can be interesting if we look at the need for cheap asylum seeker housing²³. While aiming at revitalizing neighbourhoods it attracts people with higher education, increase social cohesion and diversify the housing stock²⁴. The idea of a lot of room for little money makes them go to run-down neighbourhoods and explore the possibilities²⁵. 'Klusers' are not on their own and are supported with a consultant, architect and coach in the process of transformation²⁶.

Coming back to the surroundings, a lot of projects are set up throughout the Netherlands to enhance social cohesion, liveability, green & public space, neighbourhood development, durability, integration and living conditions²⁷. It is clear that people want and will participate in projects that affect their

¹⁴ Boelens and Visser (2011, p. 104)

¹⁵ Smithson (1968; Kroll (1987; Habraken, N. J. (1976)

¹⁶ Boelens and Visser (2011, p. 105)

¹⁷ Kracht in NL (2015, p. 9); Chen et al. (2015, p. 618)

¹⁸ Boelens and Visser (2011, p. 105)

¹⁹ Boelens and Visser (2011)

²⁰ Boelens and Visser (2011, p. 125)

²¹ Schreuders, Wassenberg, and Vos (2013, pp. 24–26); Agentschap NL (2012)

²² Users were given a budget of € 13.000 to rearrange the layout and apply finishing as they wanted. Schreuders et al. (2013, p. 25)

²³ The government wants to keep the housing sober in

order to lower cost and prevent a large financial burden on the Dutch society. (Kamerbrief over huisvesting van vergunningshouders, 2015), page 2

²⁴ Zijlstra and Stolwijk (2011, pp. 11–14)

²⁵ Huitzing (2011, p. 141)

²⁶ Agentschap NL (2012)

²⁷ Kracht in NL (2015, p. 9)

surroundings, but keeping them motivated is difficult due to lack of exposure and recognition of the projects²⁸. Nevertheless, these initiatives form a durable, vital and new economy in which ecological, social and economic values are connected²⁹.

Another research was done from a sociological perspective³⁰, investigating the participation of future residents in the creation of mass housing. The main aim is to give residents a sense of home to prevent a negative social impact. Low quality housing can lead to, for example, boredom, fatigue, depression and anxiety. While lack of sense of place may result in placelessness, uprootedness and root shock³¹. It is stated that homemaking should be able to provide end-users the opportunity of 'gradually assigning their humanity and existence over the environment'³².

Part of Poor's³³ theoretical model describes the personalisation freedom of housing attributes to users. Three levels are mentioned: fixed; semi-fixed and non-fixed. The link can be made with aspects of housing, for example the structure is fixed, but furniture is non-fixed and easily adapted to user needs. Because users cannot fully participate in the whole process of decision making, several participation concepts are proposed: reactive, passive or proactive participation. Obviously the latter is most important for achieving sense of place as residents participate in the decision making stage.

000.4 Airey building system

There was a large shortage of housing after the Second World War. In order to cope with replacing damaged houses, the lack of housing as well as a growing population³⁴, the Dutch government intervened in the building sector to overcome this problem³⁵. In order to build houses quickly the construction of these dwellings was done systematically and rationally³⁶. At the same time there was a shortage of traditional building materials, experienced workers and construction tools. Industrialisation and prefabricated building systems with the use of new materials was a result of this.



Figure 1 Building of Nemavo-Airey block in Amsterdam

²⁸ Kracht in NL (2015, p. 13)

²⁹ Kracht in NL (2015, p. 9)

³⁰ Poor, Sayyed Javad Asad (2015)

³¹ Translation: plaatsloosheid, ontheemding en verlies van emotionele ecosysteem.

³² Poor, Sayyed Javad Asad (2015, p. 286)

³³ Poor, Sayyed Javad Asad (2015, p. 291)

³⁴ Blom, Jansen, and Heiden (2004, p. 8)

³⁵ Boelens and Visser (2011, p. 104; Blom et al. (2004)

³⁶ Blom et al. (2004, p. 25)

The AUP³⁷ was used to expand the housing stock at the west of Amsterdam. To prevent a monotone district, several building systems and architects were involved. One of these building systems was the Airey system, imported by the Dutch government in 1948³⁸. It was used for the construction of 255 dwellings in 1952³⁹ along the Burgemeester de Vlugtlaan⁴⁰.

Previous mentioned problems within the building sector were reasonably solved with the, by Nemavo improved, Nemavo-Airey system⁴¹. Material was saved and construction time on site was reduced with 40 percent. Steel, wood and concrete were used in the production of small elements that made up the system. These elements could be lifted and attached by one person, eliminating heavy on-site equipment. Large scale production lowered the cost, but enhanced repetition. Still, a reasonable variety of dwellings could be designed with the system.

Reusing the existing has been mentioned in the problem statement and will be the starting point for the Airey blocks. Still, heavy adaptations are needed and results in some demolition of the building. It should be noted that the concept of Airey can also be seen as a heritable value, therefore this will be used in the development of this project.



Figure 2 West and east facade of Airey block

With the overall graduation project in mind, only the construction will be discussed. In the building blocks⁴², a grid in the façade and in the floors is used. The façade, made of slender concrete columns, has a grid of 625mm. Due to necessary windows and doors, columns are not placed on every grid line. Floors are resting in an UNP-beam that is attached to façade columns and a beam in the middle, making the span roughly 4,25 metres. Within this floor, steel lattice girders (tralieliggers) made of two flanges and thick steel wire are placed on a grid of 545mm.

³⁷ The 'Algemeen Uitbreidings Plan' was originally created in 1935 by Cornelis van Eesteren due to housing shortage in Amsterdam. The idea behind this plan was the 'garden city', by Ebenezer Howard, with the

use of a lot of greenery. Blom et al. (2004, pp. 12,16)

³⁸ Blom et al. (2004, p. 26)

³⁹ Messchaert, Martin, Heddema, and Meurs (2004, p. 23)

⁴⁰ The Nemavo-Airey system was used in many places in the

Netherlands as well as Amsterdam. Messchaert et al. (2004, pp. 12–31)

⁴¹ Messchaert et al. (2004, pp. 8–10)

⁴² Baltussen (2012, pp. 19–27; Hooyschuur architecten BNA (2012)

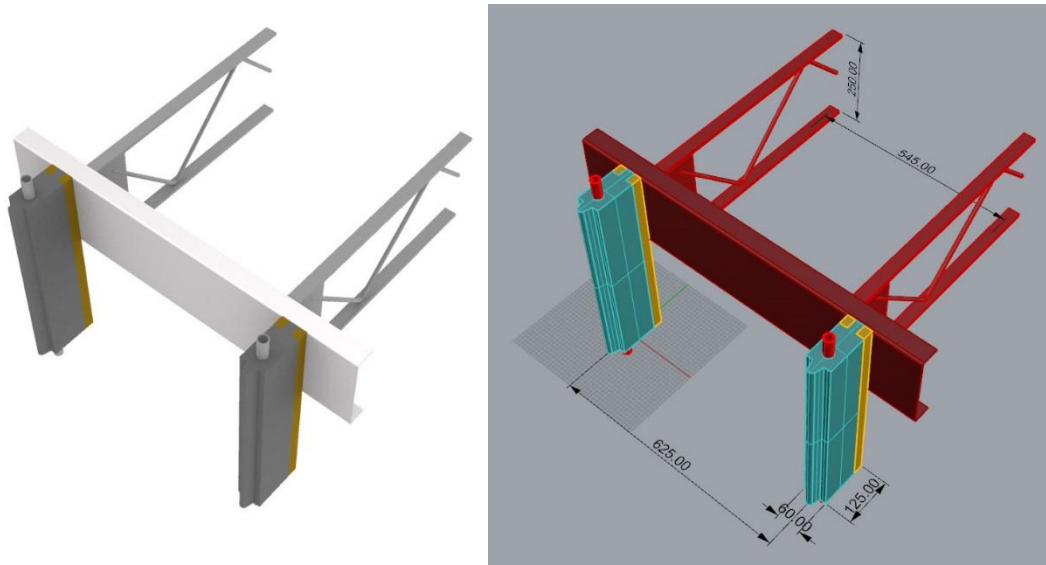


Figure 3 3D drawing of columns & beams + dimensions

Because the system is from over 60 years ago and was designed during a different time, problems arise today⁴³. Technical standards were lower back then, resulting in a low insulation value today. Lightweight floors result in sound nuisance between dwellings. Residents find the dwellings way too small and the public space is experienced as anonymous. Renovation plans are made yet not here discussed, because the goal of this project is to give a new perspective on the Airey blocks.

000.5 Conclusion

While it was normal for the consumer to take a passive role and find a home to what is available on the market or what corporations allocate, this role seems to be changing. People want more influence in their environments and therefore participate in projects or reconstruct existing houses to suit them better. While these physical benefits are clear, there are also sociological benefits. Social cohesion is better, while people have a better sense of place and want to live longer in the same dwelling.

The Nemavo-Airey system is used in the AUP after the Second World War to build cheap dwellings with a mass produced prefabricated modular system using unskilled workers and no heavy equipment. Today problems arise with insulation, sound nuisance, limited floor area and a dreary look of the building blocks.



Figure 4 Nemavo-Airey blocks currently

⁴³ Messchaert et al. (2004, p. 45; Baltussen (2012)

001 HISTORY OF PARTICIPATION

Time and again it has been tried to convert modern architecture into a commodity, away from elitism, historicism and anti-industrialism that characterized the profession in the nineteenth century⁴⁴. Le Corbusier, with the Modern Movement, definitely was the father of this idea⁴⁵ and since then it has been used in each generation of architects⁴⁶. Failure to have a lasting impact on the architectural field were due to several reasons which we will discuss.

001.1 First half of the twentieth century

When talking about mass production in architecture often the link is made with the car industry. Le Corbusier initiated this idea with his Dom-ino construction framework which is seen as an icon within architecture. These frameworks would be constructed by contractors and could later be completed with the choice of mass produced components selected by either the client or an architect⁴⁷.

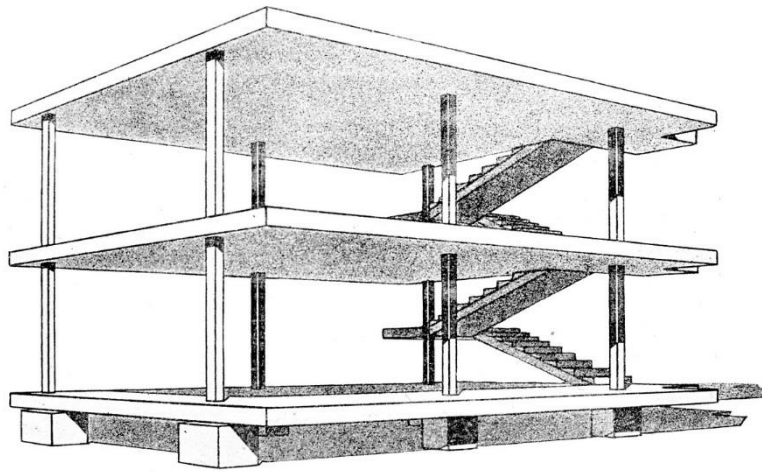


Figure 5 Dom-ino, 1914, Le Corbusier

Many architects have since tried to make industrial prefabricated houses. Among them are well known names such as Gropius & Wachsmann, Buckminster Fuller, Frank Lloyd Wright and Jean Prouvé. They all suffered difficulties, ranging from: overdesigning^{48,i}; getting cold feet^{49,ii}; not aiming for full prefabrication^{50,iii}; being more a technician than architect or lacking entrepreneurial knowledge^{51,iv}.

Another important reason is not meeting the promised economic advantages, which is used by architects as an argument many, many times. Russell describes⁵² this economic motivation as the main problem with mass produced architecture. Repetition is inevitable and even with great quantities the savings are marginal. Besides, a certain quantity is needed for mass production to be feasible and with a durable product like housing this is difficult to achieve⁵³.

⁴⁴ Davies (2005, p. 11; Kieran and Timberlake (2004, p. 105; Russell (1981, pp. 669–671)

⁴⁵ Kieran and Timberlake (2004, p. 105); Davies (2005, pp. 11–15); Russell (1981, p. 125)

⁴⁶ Kieran and Timberlake (2004, p. 105; Russell (1981, pp. 669–679)

⁴⁷ Russell (1981, pp. 125–126)

⁴⁸ Russell (1981, pp. 143–144; Davies (2005, pp. 19–25)

⁴⁹ Davies (2005, pp. 25–29)

⁵⁰ Davies (2005, pp. 29–33)

⁵¹ Davies (2005, pp. 33–34; Russell (1981, pp. 149–158)

⁵² Russell (1981, pp. 672–677)

⁵³ Houses are not bought by the 10.000 every year, or at least you wouldn't want such a quantity of the same housing.

Eventually the utopian ideas weren't popular with the masses due to the industrial look⁵⁴. Exemplary is a group of houses built in 1925 for M. Frugès⁵⁵. Due to unpopularity they were given to the poor which then altered the dwellings, ironically with mass produced products.

The problems mentioned are wrapped together with a statement made by Kieran and Timberlake⁵⁶: 'Individual circumstances of cultural heritage, personal preference, and particulars of site, while not consistent, are always present and will always work against any impulse toward a common, repetitive appearance and substance for all production.'. Only when need is critically high, such as after the Second World War, are people willing to accept the simplified aesthetic of industrial mass produced houses and the idea is feasible⁵⁷.

001.2 Second half of the twentieth century

After the Second World War the idea of industrialised production didn't fade away, but the connection with choice for the user did. Architects focussed on theorizing in the 1970s⁵⁸ with for example Team 10, Lucien Kroll and Habraken. Participation and influence in the general discussion differ, but these three show what was going on. The practicality of their theories was minimal to quite feasible and is a good start for comparison.

001.2.1 Theory

Team 10, consisting of many well-known architects⁵⁹, had the aim to bring back the individual in mass housing and s/he could again be master of their home⁶⁰. They argued that houses are built to the smallest detail and men is pressed into it, which enlarges the problem of identity. The theory they proposed was not to be seen as reality, but left room for architects. Still, new forms needed to be found as historical forms were no longer existing. Interesting are the levels at which they theorize: 'Urban infrastructure', 'Grouping of dwellings' and 'Doorstep'. The individual thus has several levels on which he has an identity.

001.2.2 Practice

Kroll and Habraken are good examples of actually enabling the user to participate in the creation of his dwelling. Levels of participation differ as Habraken's vision is much more a framework for projects⁶¹, while Lucien Kroll realised projects himself⁶².

Famous example of this is his Social Centre (Mémé) which was realised between 1970 and 1976 in Brussels⁶³. Students were involved in the creation of the student housing complex. Differentiation, avoidance of repetition and genius loci were the goals. Some kind of grid was needed to coordinate the project and the SAR module of 10 + 20 centimetre was used. Columns were placed on a grid of 90 cm, but were not placed in a line. The interior was made removable with moveable partitions and prefabricated sanitary units. On the exterior demountable windows were used. Students were asked to participate in placing partition walls and designing the windows.

⁵⁴ Russell (1981, pp. 125–159, 1981, p. 697, Kieran and Timberlake (2004, pp. 105–109)

⁵⁵ Davies (2005, p. 17; Russell (1981, pp. 131–132)

⁵⁶ Kieran and Timberlake (2004, p. 109)

⁵⁷ SOURCE?

⁵⁸ Davies (2005, pp. 40–42)

⁵⁹ Jaap Bakema, Georges Candilis, Giancarlo De Carlo, Aldo van Eyck, Alison and Peter Smithson and Shadrach Woods are seen as the core members of Team 10, but many more

were present during meetings. Heuvel, Dirk van den and Risselada (2005)

⁶⁰ Smithson (1968, pp. 74–83)

⁶¹ Boekholt, J. Th. (1974)

⁶² Kroll (1987)

⁶³ Kroll (1987, pp. 38–63)

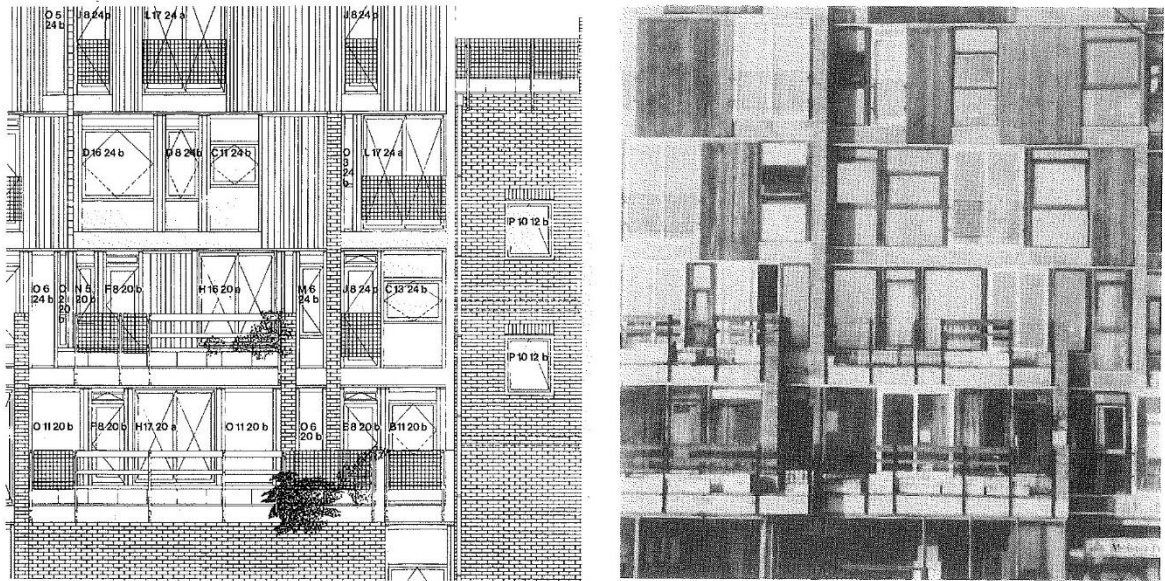


Figure 6 Facade of MéMÉ, Brussels⁶⁴

The SAR module was a result of research done by the Dutch Stichting Architecten Research⁶⁵. This again was a result of Habrakens' theory for user participation in mass housing. His framework⁶⁶ surrounds user participation in new build and (future) existing buildings. Extensive research by him as well as colleagues and the Dutch Foundation for Architectural Research⁶⁷ have contributed to a well crystallised theory for city planning, building block design and interior systems. The theory eventually was used in the design and construction of several buildings⁶⁸.

001.2.3 Habrakens' framework

The thought of Habraken, as well as Kroll and Team 10, was to provide a semi-finished dwelling which the user could complete. He should only focus on the layout and facades of the dwelling.

Buildings are divided into zones that can suit certain functions⁶⁹. Between these zones there is a margin. For the described zones you have the following types: alfa (α) or beta (β) for inside the dwelling and gamma (γ) or delta (δ) for outside the dwelling. There are several rules for the zones that give the designer more freedom: [1] A zone does not have to be straight; [2] A zone does not have to be evenly wide everywhere; [3] A zone can have a width of zero.

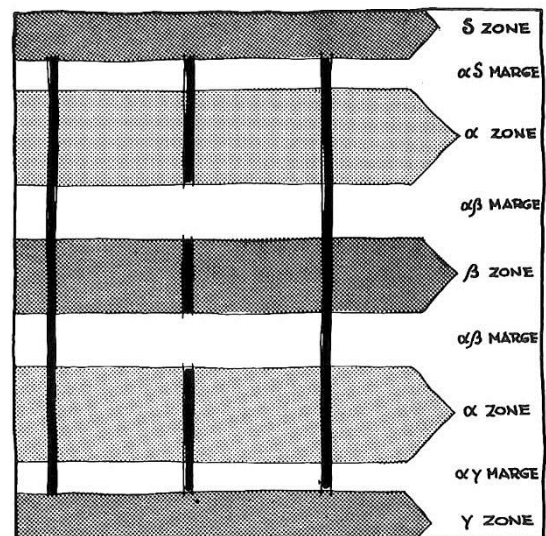


Figure 7 Different zones within the layout

Alfa zones will be used for functions that require daylight or access from outside, while beta zones will not require daylight. The gamma zone is on the public side of the dwelling, while the delta zone is at the private side. The margins between alfa or beta can be used for the desired rooms or be used as a hallway. Due to the possible functioning as a hallway the construction should be omitted here. Margins between alfa and gamma/delta zones are meant for facades.

⁶⁴ Kroll (1987, pp. 52–53)

⁶⁵ Kroll (1987, p. 56)

⁶⁶ Boekholt, J. Th. (1974)

⁶⁷ Boekholt, J. Th. (1974, p. 7)

⁶⁸ Werf, Frans van der. (1993)

⁶⁹ Boekholt, J. Th. (1974, p. 47)

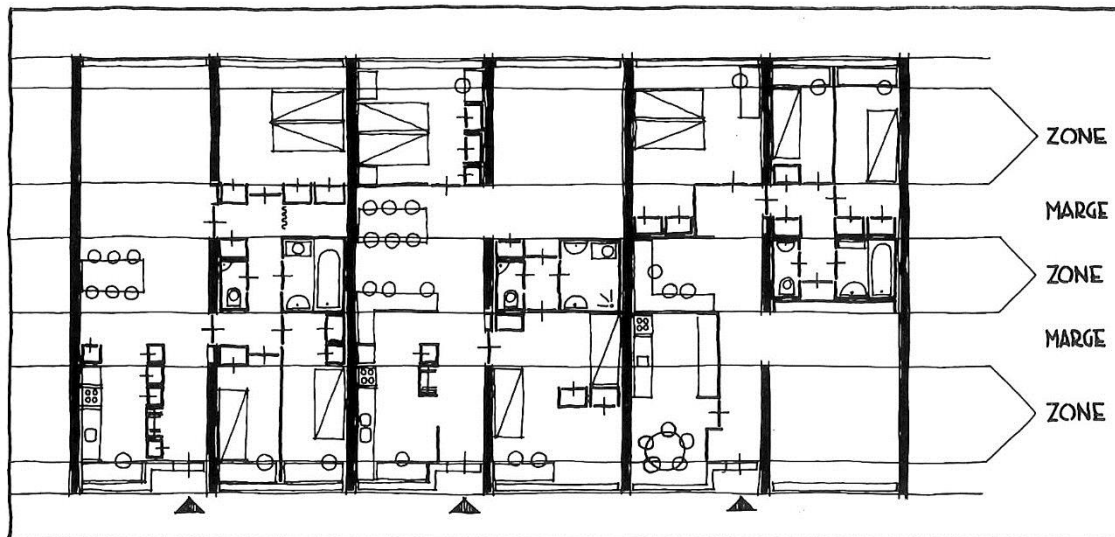


Figure 8 Zones and margin with filled in layout

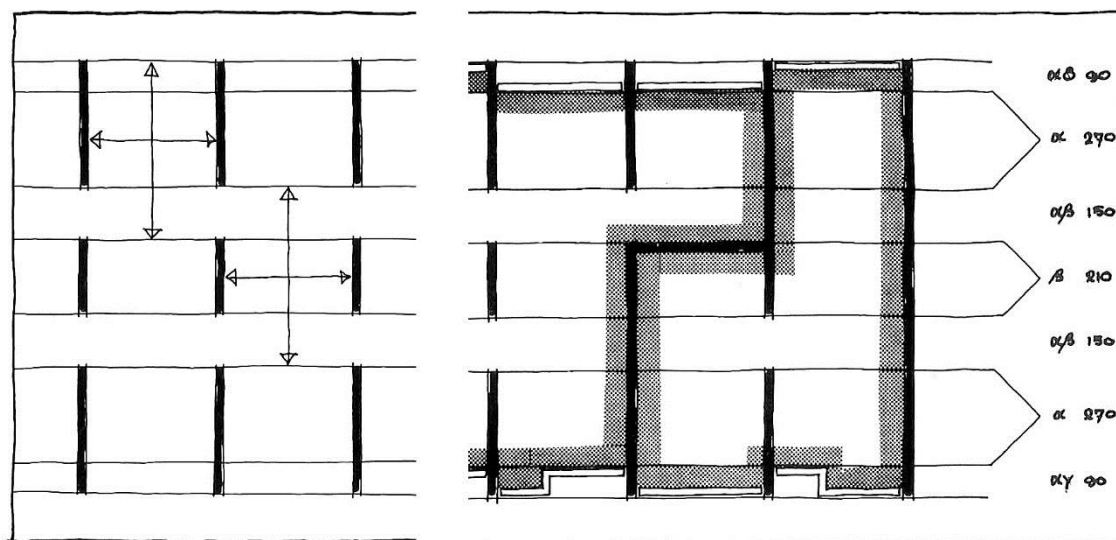


Figure 9 Left: grouping of zones, right: cluster of groups

A sector is a cluster of zones that are situated between the same structural elements⁷⁰. The depth per zone can still vary. One dwelling is made up of a cluster of groups. It is possible that a dwelling only has one sector, but it is suggested that this happens rarely due to structural limitations.

Eventually the designer has to make preliminary layouts for the dwellings in order to test his previous choices for the width of the sector and depths of each zone. With this design the layout consists of placing certain functions in the plan, but it is possible for some functions to be altered later by the user. A bedroom for example can easily be joined with a living room if wanted.

A grid with an altering width of 10 and 20 centimetre is used to coordinate the construction and interior systems. Material should be placed in such a way that it ends in a 10 cm band.

In the end it is the user that defines his or her interior of the dwelling. Suggestions are already made by the architect, but alterations are possible. Boekholt shows us an overview for configurations of furniture and to what room dimensions this leads too⁷¹ which are not so different than the ones

⁷⁰ Boekholt, J. Th. (1974, p. 42)

⁷¹ Boekholt, J. Th. (1974, pp. 73–75)

made by Neuferts'⁷². These suggested arrangements could help the end-user in the first design phase in which he defines a rough layout of the dwelling.

001.2.4 Habraken's framework in practice

Many people within the building sector saw potential in the concept of Habraken and accordingly thousands of dwellings were realised based on this paradigm. Still we don't hear a lot about it today⁷³. Van der Werf (1993) did research regarding the state of the paradigm. He sees a bright future for the paradigm, but sees some hurdles that need to be taken⁷⁴.

Developers see potential, but don't want to make the building process more complex than it already is with components they have no experience with. The involvement of users is also not received with open arms, being it not one of their tasks or afraid for excessive designs. Rising cost is another much heard argument, but realised projects counter this. Last reason is that architects don't see it as the role of the user to define the dwellings layout. They are used to designing everything from start to finish and are educated for an unknown end-user.

001.3 Conclusion

Built examples for user participation were using industrial manufacturing in which the concepts failed due to various reasons, related to the personal abilities of the architect and the desire for an all-embracing system. Main problems are linked with no economic savings and linking the industrial production with the aesthetics of the Modern Movement, which were not popular with the common worker.

Conceptualising and putting participation on another level managed to keep more of the original architecture standing and thus making it more popular with the general public. Still, manufacturers are not keen on the concept due to added complexity or inexperience. Moreover, architects don't want to give away some tasks they were thought to do.

⁷² Neufert is well known for his 'pattern' books in which he describes various aspects of buildings in a systematic way.

⁷³ At least while studying, maybe the concept has dissolved in practice and not explicitly mentioned.

⁷⁴ Werf, Frans van der. (1993, pp. 158–159)

002 PARADIGMS

The aforementioned history of participation talks about industrial building methods with the aim to make architecture available for the common worker. The building systems used the same paradigm as the exemplary car industry. To understand this better, four industrial production paradigms are discussed shortly.

002.0 History & background

Due to changing demand of customers since the introduction of mass production and evolving manufacturing techniques four major paradigms have been identified: Craft Production, Mass Production, Mass Customisation and Mass Personalisation⁷⁵. Each newer paradigm will use the prior paradigms and demand more responsive manufacturing systems⁷⁶. Therefore they are an addition and don't replace previous paradigms⁷⁷.

Craft production was a pull-type production⁷⁸ where the customer would go to the manufacturer or crafts man and requested the product he desired. Traditionally, craft production was carried out by experts that learned their skills on the job in a master-apprentice relationship⁷⁹. Not every product was seen as unique, similarities were present in learned production methods. Craftsmen would have a small customer base, mainly their local community.

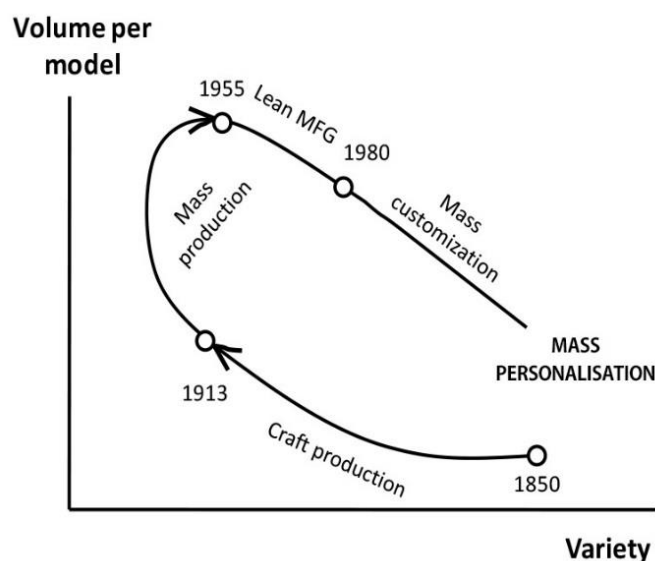


Figure 10 Volume/variety relationship in manufacturing paradigms⁸⁰

⁷⁵ Daronkola and Tavrou (2014, p. 93; Chen et al. (2015; Koren, Shpitalni, Gu, and Hu (2015; Tseng, Jiao, and Merchant, M. Eugene (1996; Tseng, Jiao, and Wang (2010; Hu, S. Jack (2013)

⁷⁶ Hu, S. Jack (2013, p. 7)

⁷⁷ Chen et al. (2015, p. 619)

⁷⁸ Daronkola and Tavrou (2014, pp. 93–94)

⁷⁹ Chen et al. (2015, p. 618)

⁸⁰ Hu, S. Jack (2013, p. 4); Daronkola and Tavrou (2014, p. 93)

002.1 Mass Production

The main goal of mass production is to produce at very low cost with large quantities of the product. Mass production requires standardised products that are manufactured in a large plant according to a specific design and are 'pushed' onto the market. Influence of the consumer on the end product is very low⁸¹.

With the Ford T, the moving assembly line was introduced. Next to this are interchangeability of parts, for making production on an assembly line possible⁸², and scientific management, done to improve 'economic efficiency, in particular, labour productivity'⁸³.

Because of the main goal, pursuit of productivity, manufacturers designed products and pushed them to the consumer with only limited input from them. The division of labour also caused problems between management and workers. Specialisation of workers tasks led to not seeing the value of their work and the contributions to the final products⁸⁴. Today this problem still exists⁸⁵.

002.2 Mass Customisation

Manufacturers started in the 1980s enhancing mass production to offer options for customers who wanted variety and influence in products⁸⁶. Therefore products can be closer to what customers want, while still maintaining the low cost and high quality benefits of mass production⁸⁷. Added benefit is the possibility to broaden the target group for a product⁸⁸.

Two strategies for mass customisation are proposed⁸⁹. Off-the-shelf variety of customized products, like clothing, or standard options installed on customized products, like personal computers. Options are mainly a collection of known components, modules or subsystems⁹⁰.

A Product Family Architect^v is the main driving force of Mass Customisation and is enabled by identifying patterns of customers' needs after which families of product with subassemblies and modules can be designed. The various elements of design and manufacturing can be reused to match customer needs with product variety^{91,92,93}. By narrowing the spectrum of product designs, variations are reduced and reusability is optimized⁹⁴.

Second is a reconfigurable manufacturing system^{vi} in order to cope with the difference between products^{95,96}. Computer controlled manufacturing made it possible to implement customisability in products to suit customer needs.

Third is delaying differentiation^{vii} which is implemented to 'delay the point where the different products take in their unique characteristics'⁹⁷. While the assembly is optimised, differentiation still adds a lot of complexity⁹⁸.

002.3 Mass Personalisation

Due to new manufacturing technologies modules can be made more specific to the customer needs. Because the paradigms is fairly new, it isn't fully thought through yet and one author seems to dominate literature. Therefore the discussion below is a mix of several articles and the authors own

⁸¹ Daronkola and Tavrou (2014, p. 94)

⁸² Hu, S. Jack (2013, p. 4)

⁸³ Hu, S. Jack (2013, p. 5)

⁸⁴ Hu, S. Jack (2013, pp. 4–5)

⁸⁵ Mass production in Asia is still causing psychological problems for workers.

⁸⁶ Daronkola and Tavrou (2014, p. 94); Hu, S. Jack (2013, p. 5)

⁸⁷ Chen et al. (2015, p. 618)

⁸⁸ Tseng et al. (2010, p. 175)

Tseng et al. (1996)

⁸⁹ Daronkola and Tavrou (2014, pp. 94–95)

⁹⁰ Tseng et al. (2010, p. 176)

⁹¹ Tseng et al. (2010, p. 175)

⁹² Hu, S. Jack (2013, p. 5)

⁹³ Tseng et al. (1996, pp. 155–156)

⁹⁴ Tseng et al. (1996, p. 154)

⁹⁵ Hu, S. Jack (2013, pp. 5–6)

⁹⁶ Daronkola and Tavrou (2014, p. 95)

⁹⁷ Hu, S. Jack (2013, p. 6)

⁹⁸ Hu, S. Jack (2013, p. 6)

view on the subject⁹⁹. Moreover there isn't one name^{100,101}, but we will use 'mass personalisation' from the perspective of the customer.

Mass personalisation is a paradigm where customers have more influence and participation in their end product¹⁰². The modular approach as within mass customisation is expanded and enables modules to be produced by other vendors. This is seen as an open architecture and enables customers to be involved in the design of their individual products. The number of options depends on the creativity of many vendors that produce modules¹⁰³.

To further enable mass personalisation, on-demand manufacturing systems¹⁰⁴ and responsive cyber-physical systems¹⁰⁵, product simulation/certification, manufacturing and supply process is needed.¹⁰⁶

The Open Architecture Platforms (OAP) aim^{viii} is to enable adding modules to the original structure or be swapped in order to change product features¹⁰⁷. An OAP consists of three levels^{108,109,ix}: [1] Platform modules; [2] Customised modules; [3] Personalised modules. Their functions respectively are: critical functions, chosen from predefined options, or personal designed/fitted modules¹¹⁰.

The modular architecture has two possible approaches: [1] Internal: keeping the personalisation as a task of the manufacturer; [2] External: Open Architecture Platform¹¹¹: enable outside parties to make personalised modules for a product. These outside parties may be [a] other vendors or [b] the customer.



Figure 11 User involvement explained in diagram form

⁹⁹ For several articles, critical notes were made to the proposed frameworks. Moreover most literature is influenced by Koren, making his view dominant. Appendix A shows critical notes on OAP.

¹⁰⁰ Koren et al. (2015, p. 65; Daronkola and Tavrou (2014, p. 95)

¹⁰¹ Mass individualisation, one-to-one marketing, one-of-a-

kind production, market-of-one, mass collaboration are just a few.

¹⁰² Hu, S. Jack (2013, p. 4; Koren, Hu, Gu, and Shpitalni (2013, p. 720; Daronkola and Tavrou (2014, p. 95)

¹⁰³ Koren et al. (2013, p. 720)

¹⁰⁴ Wu, Rosen, Wang, and Schaefer (2015)

¹⁰⁵ Jiang, Ding, and Leng (2016; Sogeti VINT (2014)

¹⁰⁶ Daronkola and Tavrou (2014, p. 95)

¹⁰⁷ Koren et al. (2013, p. 719)

¹⁰⁸ Zhang, Peng, and Gu (2015, p. 267)

¹⁰⁹ Hu, S. Jack (2013, p. 6)

¹¹⁰ Koren et al. (2013, p. 720)

¹¹¹ Koren et al. (2013)

According to Koren et al.¹¹² the modules should be certified by the main manufacturer, but this hinders the ‘open’ character¹¹³. Collaboration will happen via the internet using a general database in which both manufacturer and user can see and use modules¹¹⁴. With this fully digital character it becomes possible to verify safety and reliability and perform simulations¹¹⁵. Development process of the OAP market¹¹⁶ is written in the end notes^x. New internet tools will enable on-demand manufacturing of personalised modules¹¹⁷.

User involvement can be done indirect^{xi} or direct^{xii,118}, checking functionality or participating in the design process¹¹⁹. It is impossible for an ordinary user to participate in the design process due to lack of skill and knowledge thus a simplification needs to be made.

002.4 Conclusion

Based on literature¹²⁰, the paradigms can be compared:

	MASS PRODUCTION	MASS CUSTOMISATION	MASS PERSONALISATION
BUSINESS MODEL	Push	Push-Pull	Pull
MODEL	Economy of Scale	Economy of Scope	Value Differentiation
CUSTOMERS’ ROLE	Buy	Choose design	Design
VOLUME	Large volume	Moderate	Several/one
MANUFACTURING	Dedicated	Reconfigurable	On-Demand
PRODUCT BUILT	Identical product	Product with options	Customer designed
PRODUCT ARCH.	Unified	Modular	Open platform
PROPERTIES	Quality Low cost	<i>Quality</i> <i>Low cost</i> Variety	<i>Quality</i> <i>Low cost</i> <i>Variety</i> Efficacy
DRIVING FORCES	Assembly line Interchangeability Scientific management	Reconfigurable manuf. Delaying differentiation Product Family Arch.	Open platform User involvement On-demand manuf. Cyber connected

Table 1 Comparison of different product production paradigms

When user demands and technology evolved, so did emerge a new paradigm. Still, today each paradigm has a purpose and newer ones didn’t replace older paradigms. Mass production for example can be sufficient in product which don’t require user influence.

With the graduation project in mind, mass personalisation is most useful, but use of previous paradigms is logical in certain aspects of the building.

¹¹² Koren et al. (2013, p. 720)

¹¹³ A more elaborate reflection is placed in the end notes (ix).

¹¹⁴ Hu, S. Jack (2013, p. 7)

¹¹⁵ Hu, S. Jack (2013, p. 7)

¹¹⁶ Koren et al. (2013, p. 722)

¹¹⁷ Hu, S. Jack (2013, p. 7; Chen et al. (2015, pp. 615–619; Wu et al. (2015, pp. 1–3)

¹¹⁸ Zhang et al. (2015, pp. 268–270)

¹¹⁹ Visualisation tools are needed, for example VR. Hu, S. Jack (2013, p. 6; Zhang et al.

(2015, pp. 269–270; Koren et al. (2015, pp. 67–68)

¹²⁰ Hu, S. Jack (2013, pp. 6–7; Tseng et al. (2010, p. 177; Koren et al. (2015, p. 66; Koren et al. (2013, p. 726; Chen et al. (2015, pp. 618–619)

003 PARTICIPATION TODAY

Maybe you've seen some links starting to emerge between the discussed literature topics. This now will be made explicit in textual table form and next translated into a diagram on how the realisation of participation in the Airey dwellings should commence.

003.0 Background

Mass personalisation proposes a framework for user participation in the design stage. While this role will be pretty limited¹²¹, involvement still helps in achieving the sense of place. It is important to prepare the dwelling to the point where the user can take over in becoming the master of his or her home¹²². Key aspects of the Airey system are applied in involving the user: modular system, easy to assemble and lightweight components.

Failure is always an option, but knowledge of previous attempts can prevent failure. The theory of Habraken is therefore a good starting point. He did not desire an all-embracing building system and knew what users found important and what not: mainly the interior (functioning) and next facades (aesthetics). This was also proven with the found literature. Moreover the concept has been researched and tested extensively as well as used for the creation of thousands of dwellings¹²³.

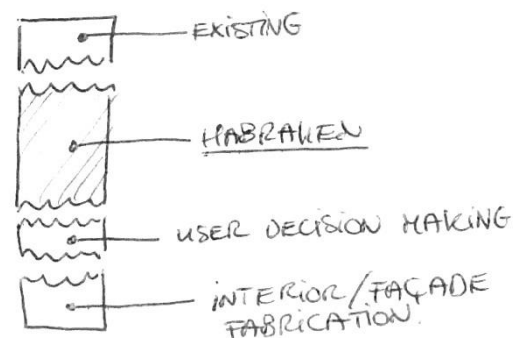


Figure 12 Schematic adaptation of Habraken's framework

Still, Habraken's framework did not catch on in the building industry. We need a new approach to the problem with manufacturers that supply the interior system. Moreover, also due to the changing building sector, architects should change their role within the building process.

Firstly, architects are no longer designing from chair to city, but should help users enable their needs. Analysis and statistics can help a great deal, but the average does not suit the extremes. Moreover, the architect is searching for a new role in today's building sector. It is possible that his or her role shifts from merely designing towards keeping the social perspective included in projects. People want more influence in their environment¹²⁴ and this graduation project is reaching for the feasible limit of user participation with a redefined role of the architect enabling it.

Architects design modules in collaboration with the manufacturer. The architect is also project manager and consultant at the same time. He oversees the project and helps, where needed, users in configuring their dwelling.

With the Mass Personalisation paradigm, direct digital manufacturing was introduced. This can solve the manufacturing problem as no large plant is needed. Even a one-off market¹²⁵ can be financially feasible¹²⁶, therefore the economic arguments of mass production are not needed. Still, the three levels of module type (platform, customised, personalised) need to be taken into account. The idea

¹²¹ Team 10 and Habraken saw that it would be impossible for men to construct their own home. A simplification is needed. Smithson (p. 74; Habraken, N. J. (1976)

¹²² Smithson (p. 76; Habraken, N. J. (1976; Kroll (1987)

¹²³ Werf, Frans van der. (1993, pp. 155–168)

¹²⁴ Seen with participation in local projects or just choosing prefab concepts like iQwoning.

¹²⁵ Market of one where only one buyer is available for a specific product.

¹²⁶ Kieran and Timberlake (2004, p. 113)

of certain types of modules can be applied in the building to make sure the user is involved in the aspects that he wants. Platform modules are the functional parts of a building. Customised and personalised modules are what you'd expect. Choosing options or either editing or designing new modules.

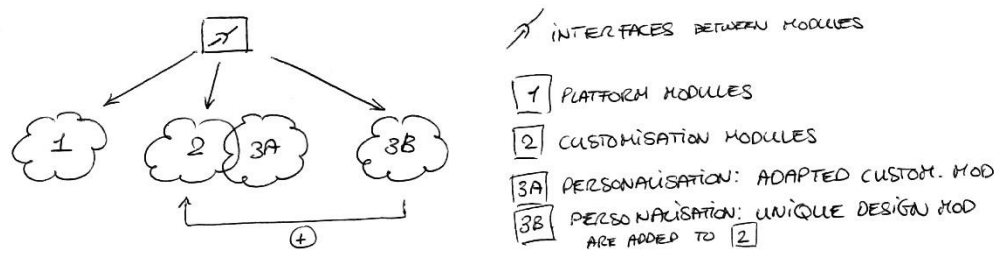


Figure 13 Type of modules, related to each other

CNC milling will be used as production technique. Architects and manufacturers are familiar with wood as a construction material and future adaptations are easily done, it's just wood¹²⁷. Other direct digital production techniques like the 3D Printed Canal House¹²⁸ are in a very early stage, while plastics make production difficult for people and construction. Printed concrete¹²⁹ is another option, but has insulation and weight problems, and is mainly focused on rough construction work (for now).

Using a cyber-physical environment ensures that modules automatically can be verified¹³⁰ and sent to production machines. A database helps connect both architects, manufacturers and users as well as store the different type of modules.

Architect (A), manufacturer (M) and user (U) are involved in the process. The architect is seen as the overall designer that supervises the process and is therefore also project manager. He also fulfils a role in the manufacturers part, therefore linking his design and manufacturer skill. The manufacturers' team is complimented with two persons that build up knowledge of the production technique. Ideally these are future residents of one of the dwellings.

Modules are designed by the architect which means a loop will be present where knowledge of the production technique is serving in the design process, preventing failure later on.

For new modules, criteria are presented by the user. From these a design will be made and tested, which results in improvements of the design. A scientific design method is presented that enables the designer to make more rational choices¹³¹. When the design is finished, parametric options are specified and the module is added to the database.

It is possible for residents to change their dwelling in the future. Because the building process will be repeated, a lot of modules will be designed and created. Therefore a large database is available at the end of the project, which can be preserved for the future. Moreover, with workshops like FabLab¹³² it is possible to fabricate modules without the initial manufacturing team and machinery.

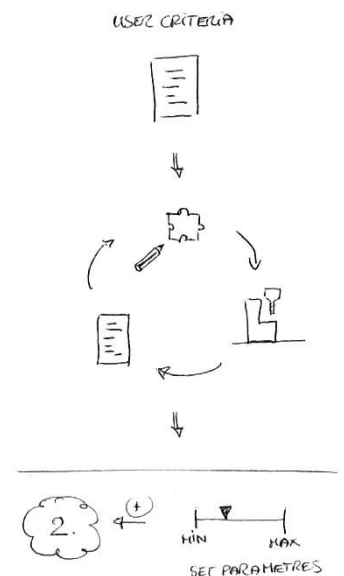


Figure 14 Rough design process of modules

¹²⁷ It's easy to cut, glue or screw things into wood. Even for inexperienced people it's possible to DIY with wood.

¹²⁸ DUS architects (2016)

¹²⁹ Salet (2015)

¹³⁰ Appendix B: Criteria for verification.

¹³¹ Knaap (2016, pp. 64–71)

¹³² 'A Fab Lab (fabrication laboratory) is a small-scale workshop offering open access

With all these points in mind the following approach can be taken to let users participate in the design of their Nemavo-Airey 2.0 dwelling. The proposed framework will be called UPHome, standing for User Participation Home. Details per step will be given afterwards.



#	Step	Inv.*	D**	V***	Explanation
1.	Analysis of Airey building block	AMU	X	X	Analyse components of building system. Determine what construction can be left standing in order to enable participation.
2.	Collect users	AMU			Get target groups together that are willing to participate in the creation of their dwelling.
3.	Make a preliminary programme of requirements (POR)	AMU			Collect all requirements from users to be able to make a rough planning of users throughout the blocks.
4.	Design a rough layout for the block	AMU	X		Plan the users throughout the block. Specify the placement of separation walls and sound insulation between dwellings.
5.	Design functional zones in blocks	AMU	X	X	Make rough planning of dwellings with assignment of zones.
6.	Design a rough layout + involve user	AMU	X	X	Place the functions in a rough sketch to determine the placement of technical functions like plumbing and wiring.
7.	Let user design the configuration of the dwelling	AMU	X	X	The user is able to further take the design upon him, selecting customised or personalised modules.
8.	Prepare and send files to machine + Assemble cut wood	AMU			Assembly of the cut wood by user, manufacturer or combination of both. First install type 1 modules, then it is possible for user to take over.
9.	Finish dwelling	AMU			Finer details can be done by the user him- of herself.

Table 2 Broad steps for realisation

* Involvement per actor in the overall process; ** Design of modules; *** Verification needed

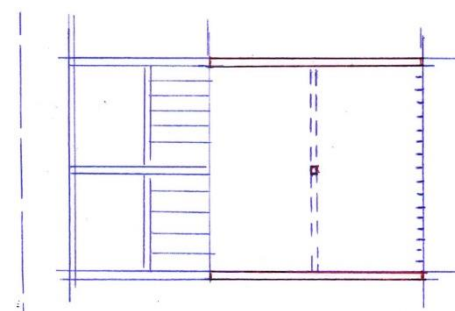
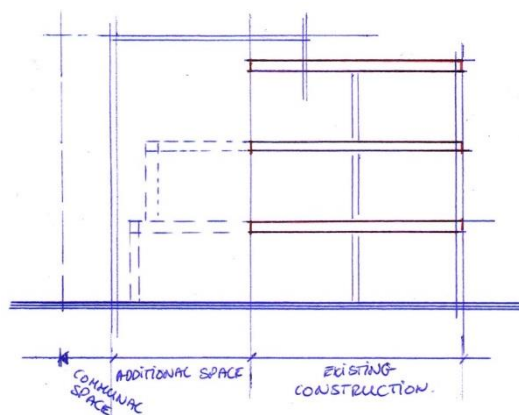


Figure 15 Starting point of skeleton structure

003.1 Analysis of Airey building

It is necessary to analyse the existing in order to adapt it where needed to suite the theory of Habraken. The project will start with the skeleton like structure which needs added modules to have basic functionality. Therefore preliminary designs for platform modules and interfaces will be made. As the project progresses, these designs will become more refined as more details are known.

Floors need modules between each beam with the possibility of laying plumbing and cables. The façade should be altered with an interface to add future modules. Last is the added space at the yard is enabled with a new construction. Ground floor and roof will be adapted as well, but with no adaptability possible.

003.2 Collect users

It is important to involve the user earlier in the building process. He or she may have certain wishes that influence the installation and construction of the dwelling. Exact locations for these aspects are not necessary, but a rough estimate is needed. For this we need a programme of requirements.

The target groups in this project are statushouders¹³³, young starters and single/two person households. These are selected on willing to participate and likely to adapt the dwelling later on. The dwellings will remain to be rental apartments. Therefore not everyone has to move out and statushouders can live in the block.

003.3 Make a preliminary programme of requirements

The Programme of Requirements (PoR) is important for the project as it is data that can be used to automate processes. By asking users questions about qualitative elements, what does or doesn't he want, and about what he most likely wants, for example a living room facing south, it is possible to gather data for semi-automatization of designing the dwelling and aid the user.

Demands and wishes need to be defined. These can be either qualitative, comply or not comply, or quantitative, meeting criteria more or less¹³⁴. Demands are the minimum criteria with which a design should comply, whereas wishes are the maximum that should be achieved¹³⁵.

003.4 Design a rough layout for the block

Using the PoR the building blocks can be roughly planned with the collected users in mind. It is for example possible to place people at ground level, or higher up. Also the size of the dwellings can be arranged for each level. Lastly, dwellings can be combined to create more space for the user.

003.5 Design functional zones in blocks

To further cope with the installations, zones are placed in the building. Now it becomes possible to plan more exact for the running of cables and plumbing. This also helps in designing the dwellings' layout.

003.6 Design a rough layout for the dwellings + involve user

Based on the zones and PoR, a preliminary design can be generated on which the user can continue. If a user would be given just an empty dwelling it would be difficult for him or her to start the design process. Obviously we work from a coarse to fine granular design.

¹³³ Asylum seekers that have been granted a longer stay, approx. 5 years, in the Netherlands.

¹³⁴ Roozenburg, N. F. M. and Eekels (1998, pp. 155–156)

¹³⁵ Roozenburg, N. F. M. and Eekels (1998, pp. 156–157)

003.7 Let user design the configuration of the dwelling

Now the basis is set, the user can fully take over in designing the dwelling. New tools are used, such as virtual reality (VR) and augmented reality (AR). This helps greatly in visualising the changes¹³⁶ a user makes in the design as he can see them one to one.

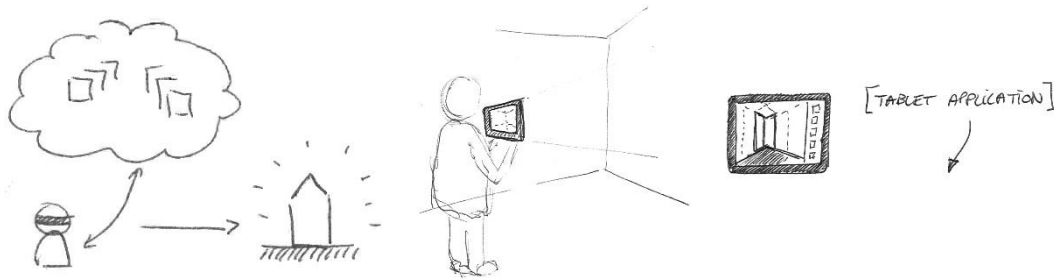


Figure 16 User involvement using tablet or VR

Users are mostly interested in the functioning of their dwellings, surroundings and architecture come afterwards. Enabling user participation in the design and construction of these parts, it is needed to provide a useful basis. A dwelling should be made to the point in which the user can take over. This point is not just finishing of walls, but the actual design like Habraken suggested.

Users may adapt the layout of their dwelling, add space and choose the facades. For these parts the customised approach can be taken: selecting from a set of options (2). It is possible to adapt the option parametrically (3A) or otherwise design a new module (3B). Newly designed modules are later added to the pool of options, thus this pool will extend over time.

The design of new modules needs to be done in collaboration with the designer, manufacturer and consultant. For this project this will mostly be the architect.

003.8 Make modules + assembly

It is possible for users to assemble their dwelling themselves, enabling more participation in the creation of their dwellings. The aim is to make it as easy as a large furniture manufacturer does right now. Still, it is possible to hire help if the assembly turns out to be too difficult.

The production of parts should be done as a file-to-factory system where no human actions are needed. Before this is possible, several revisions of a part are needed to overcome problems. Still, the power of computer technology makes it possible to automate a lot for just a first revision¹³⁷. With the new revisions of parts, knowledge can be added to the automation process to prevent similar future problems.

003.9 Finish dwelling

While a lot can be done with the adaptable modules, there are things you cannot do. The user therefore finishes his dwelling with the minor details he would like, for example carpet or painted walls.

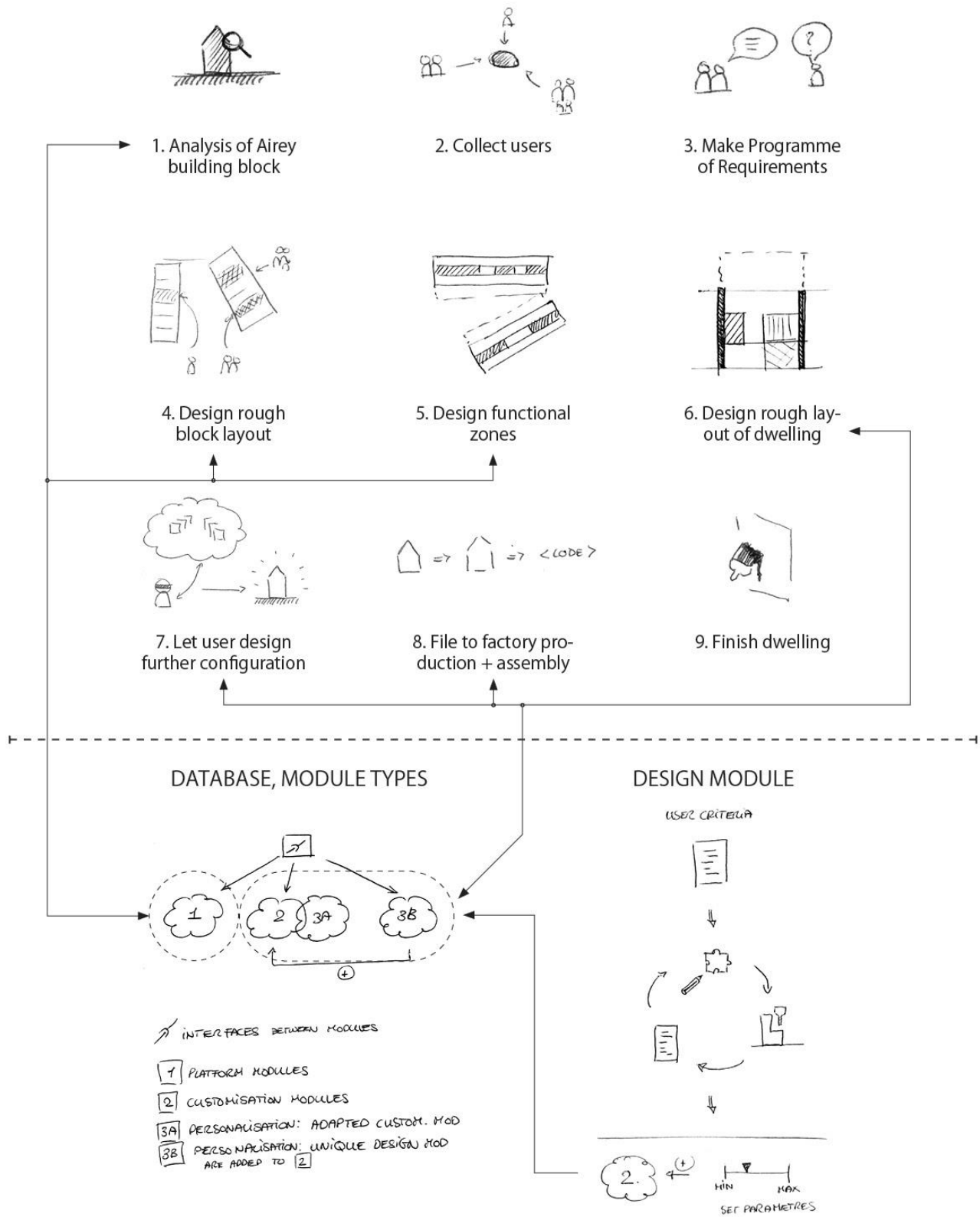
¹³⁶ Zhang et al. (2015, pp. 269–270)

¹³⁷ 'Computer technology enables architecture to make unique buildings that are

translated easily to factory produced parts.' Kieran and Timberlake (2004, p. 113)

004 PARTICIPATION PROCESS

BUILDING PROCESS



005 DISCUSSION

This paper did not dive into one specific topic, or at least the topic showed many aspects, making it a broad one. Using past projects for inspiration and to prevent failure, as well as new technologies that are present today, a framework has been developed for user participation in the Nemavo-Airey blocks in Amsterdam. This leads to the answering of the hypothesis stated in the beginning:

*Reflecting on architectural history and using modern technology,
it is now possible to implement the user in the building process.*

Yes, this is now possible. Many architects have tried to enable user participation in the past, with Habraken as the most successful example. Still, shortcomings were present which today can be overcome using new technologies like direct digital manufacturing and virtual reality.

But does this mean we should use the enhanced framework from now on for every project? No, not really. Not everyone is interested in such a heavy participation in their dwelling and are perfectly happy with a more generic dwelling¹³⁸. Still, the variety and implementation has great values for both user and society.

¹³⁸ Boelens and Visser (2011, pp. 124–126)

APPENDICES

APPENDIX A: Limitations of OAP

Enabling other manufacturers to add modules to a platform product isn't a new idea. In the 1990s General Motors and members of CIRP have thoroughly investigated the paradigm¹³⁹. Results seemed promising, but the experiment failed. Koren et al. suggests that 'modules should not be part of the core business of the platform producer', but must include all basic functions of the product. This leads to adding functions on top of the basic functionalities. Giving the example of apps on a phone that add functions to the product is simply incorrect¹⁴⁰ and it remains questionable how feasible this paradigm is.

The main concern lies with the involvement of customer in the personalisation process. This subject is more extensive than one paragraph in will be explained later on.

It is argued that OAP offers sustainability (reuse, remanufacture and recycle¹⁴¹), adaptability, upgradability and extendibility¹⁴². The sustainability argument was also made for Phoneblocks¹⁴³ but critics¹⁴⁴ said it could also be the opposite. User would sooner replace modules if they are 'more or less' outdated. Modules are cheaper than a full phone and thus the decision could be made sooner to replace a module. If people consider a module out of date it less likely that other will reuse it. Remanufacturing and recycling (which is the same) the module proposes the same problems as we usually see, but maybe it is a bit easier due to smaller component sizes. Moreover adaptability and extendibility is closely related and upgradability is heavily dependent on the interface between the platform and modules. The question should also be asked what business model manufacturers should use for an open platform¹⁴⁵.

The last problem with OAP is the assembly of products. This last step in making product shifts from the manufacturer to the customer due to the participation of other vendors. It is possible to include them in the assembly process that manufacturers cover, but this proposes problems with delivering modules in time¹⁴⁶. If the assembly is done by customer this proposes problems with the level of difficulty and may hinder the functionality of modules.

APPENDIX B: Possible automated verification aspects

Short list of possible aspects that can be checked via computer automatization.

Regulation (Bouwbesluit)

- Daylight entrance
- Size of rooms
- Presence of required rooms
- Dimensions of windows & doors
- Supply of fresh air

Production method

- Possibility to cut
- Sizes per sheet/optmise
- Cutting time

Construction

- Bending
- Stress failure

Installations

- Ventilation pipes sizes
- Shortest route of plumbing

¹³⁹ Koren et al. (2013, p. 720)

¹⁴⁰ Note that 'Apps' are software that combine hardware functions to enable new functionality of the smart phone.

¹⁴¹ Koren et al. (2013, p. 722)

¹⁴² Koren et al. (2013, p. 722)

¹⁴³ Modular phone design by Dave Hakkers

¹⁴⁴ Wikipedia (2016; Kean

¹⁴⁵ Once the platform is sold, the customer reverts to other vendors. Or should the

manufacturer make money through licencing vendors to make modules for the platform? This could result in a more expensive product.

¹⁴⁶ Koren et al. (2013, pp. 722–723)

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ⁱ In 1942 architect Walter Gropius and Konrad Wachsmann initiated an architectural approach to the prefabricated, mass produced, house. This project could be successful due to the American Veterans Emergency Programme. Unfortunately Gropius and Wachsmann didn't succeed, but were troubled with ever improvements of the design by Wachsmann, who was reaching for one true universal system which could not be produced for a reasonable cost.

ⁱⁱ During the Second World War, Buckminster Fuller was asked to produce prefabricated dwellings in an aircraft factory to boost morale of the war ending and having a future for workers having a job. Despite a lot of publicity and enthusiastic workers, Fuller eventually got cold feet with his Wichita House project. Maybe due to negative publicity if the project failed and delayed production. Eventually only one house was built.

ⁱⁱⁱ One architect that had many examples of prefabricated homes was Frank Lloyd Wright with his 'Assembled House', 'Ready Cut' prefabrication system, an all-steel prefabrication system for housing in Los Angeles and prefabricated houses according to previous designs of Wright. Only his Usonian house is remembered best in history and was meant for the average American (middle class) family, although it mostly attracted higher class people. While not being prefabricated it did resemble the rationalising attitude of Le Corbusier with continuity of an ongoing system. Standard details and a Tatami-mat based grid made design and construction a lot easier. Still, in the end not many houses were built, Wright simply wanted to rationalise the process to be able to design quickly and then hand of work to apprentices.

^{iv} Likewise as Buckminster Fuller, Jean Prouvé had a background in metal production used in houses which shaped his view on architecture and the building process. He wanted to bring techniques of the factory to the building industry using a pragmatic approach. He also didn't believe in a 'utopian' project and wanted an evolutionary approach to industrialising the building process. Eventually he didn't manage to succeed in realising a mass produced house. Maybe because he was rather a technician than an architect, having an ambivalent position in architecture, or due to entrepreneurial setbacks.

^v A product is no longer a fixed object that is produced over and over again. Due to customisability, modularity is introduced into the products' design. Some parts will be similar for all products and some will be customisable.

In order to make this happen, patterns of customer needs are identified after which families of products with subassemblies and modules can be designed. The various elements of design and manufacturing can be reused to match customer needs with product variety.

Similarities of design and manufacturing processes are identified and grouped together based on their topologies or operation processes and, if possible, by forming machine groups. By narrowing the spectrum of product designs, variations are reduced and reusability is optimized.

Next to current and future customer's needs and repeatability in design and fulfilment, ease of configuration and appropriate level of aggregation are basic building blocks of PFA. While all these parts are important for PFA, the ability to cover a group of individual product functional requirements is used to judge the capability of a Product Family Architecture. This means customer is seen as the most important goal.

Steps to formulate PFA are as follows: [1] Functional requirement (FR) formulation; [2] Density analysis of FRs; [3] Identifying design parameters (DPs); [4] Clustering DPs for building blocks: a few DPs are identified to cover the same FRs in order to fulfil diverse customer needs [5] Granularity trade-off: reach a balance between additional building blocks and customisation needs.

^{vi} By providing customisability, the manufacturing systems should be able to cope with the difference between products. Different customer needs caused by predicted or unpredicted changes, changing market demands, are the cause of this.

As discussed before the emergence of computer controlled manufacturing made it possible to implement customisability in products to suit customer needs. While modules can be mass produced, for example, the assembly of all these different modules into one product is different each time.

New manufacturing techniques emerging today enable more customisability, leading to a level of personalisation some argue, but this will be discussed later on.

^{vii} To help cope with the difference between each end product, Delayed Product Differentiation is implemented to 'delay the point where the different products take in their unique characteristics'. This means products are similar up to a certain point after which different modules are added to create the desired customisable end product.

Delaying the addition of modules helps to eliminate some complexity in the manufacturing process, but customisable products still add a lot of complexity to the assembly systems.

^{viii} The open architecture is an enhancement of the Product Family Architecture. It's aim is to enable adding modules to the original structure or be swapped in order to change product features. An OAP consists of three levels: [1] Platform modules; [2] Customised modules; [3] Personalised modules. Platform modules have basic functionalities for the product, customised modules are common functions and personalisation modules are specific suited to the users' needs. Appendix A shows critical notes on the limitations of the OAP.

^{ix} The first level, platform modules, have critical functions that are needed for basic functioning of a product. These functions are determined by the manufacturer and are always present in the product.

The second level, customised modules, have the same aim as with mass customisation. The manufacturer analysis customer needs and as a result makes several options from which the customer can choose.

The third level, personalised modules, customers are involved in designing the options of their products. These modules can be made by other vendors than the original manufacturer or be made by the customer themselves. Either way, according to Koren et al., these modules should be certified by manufacturers. Several reasons can be given for this decision, of which the main concern is product safety, but it also enables manufacturers to prevent certain modules making an 'open' architecture a little less open.

^x Developing the OAP market requires five steps: [1] The original equipment manufacturer (OEM) [...] supplies the main platform of the product with its essential functions.; [2] The OEM of an open-architecture product establishes interface standards that allow potential developers to integrate

their innovative modules; [3] Many companies develop new modules [...]. Note that the OEM must approve each module, but does not develop it.; [4] Customers adapt the product's functionality to their needs by selecting modules from different vendors.; [5] Modules are integrated into the platform of the OAP to adapt to a desired use for the customer.; [6] The last step of module integration into the platform may be carried out by the customers themselves for products that do not need safety regulations. [...] However, final assembly of complex products with safety regulations, like automobiles, will require professional assembly [S].

^{xi} The detailed design process of modules is laid aside and customers are only involved to evaluate the product functioning. A design agency is put between the customer and manufacturer to translate requirements into a design. All three parties are connected through the internet.

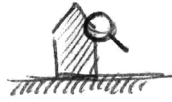
Product platform, formulating product interface and testing personalised modules are the responsibility of the manufacturer. User requirements are gathered by a design agency and translated into a personalised module, but before delivery it should verify meeting quality and safety standards. The user only has to provide their requirements to the design agency and his involvement in the design is minimal.

Modules are added to a larger pool of modules that future customer may choose from. This way, manufacturers expand their inventory as customers demand different modules.

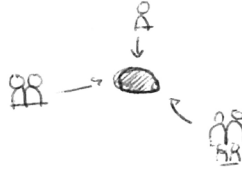
^{xii} Using new technologies such as VR, users are more able to participate in the design process. While the life cycle of a product is way more elaborate than only the design phase^{xii}, only then the user will be implemented. When a module is designed it should be verified for feasibility or manufacturing or affordability.

Benefits of using a VR-based design interface are the visualisation of design elements, improving the understanding of product design in modules and interaction with the product to test its performance.

BUILDING PROCESS



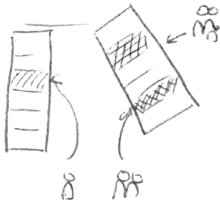
1. Analysis of Airey building block



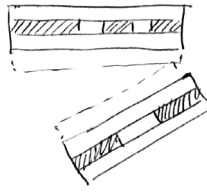
2. Collect users



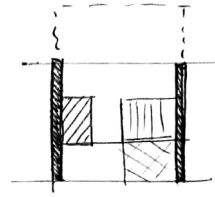
3. Make Programme of Requirements



4. Design rough block layout



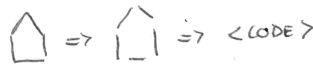
5. Design functional zones



6. Design rough layout of dwelling



7. Let user design further configuration

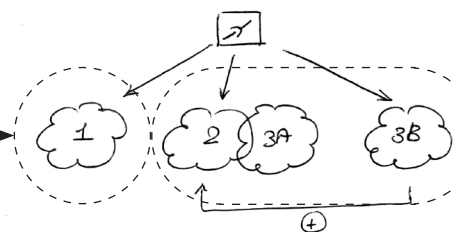


8. File to factory production + assembly



9. Finish dwelling

DATABASE, MODULE TYPES



INTERFACES BETWEEN MODULES

1 PLATFORM MODULES

2 CUSTOMISATION MODULES

3A PERSONALISATION: ADAPTED CUSTOM. MOD

3B PERSONALISATION: UNIQUE DESIGN MOD ARE ADDED TO 2

DESIGN MODULE

USER CRITERIA

