

MIND THE GAP

SINGLE-OCCUPANT HOUSING IN THE LEFT-OVER SPACES OF CITY CENTERS

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ABSTRACT

This paper represents the research done to create a design guideline for building lightweight single-occupant housing in the left-over space of European city centers under the highlight of the housing shortage issue. The research focuses on providing technical guidance on the attachment of the proposed units to the existing fabric of the chosen location. To do so, the research is twofold. It presents results on: 1. the existing and its potentials: where a material catalogue of the existing fabric is presented along with its characteristics, the type of gaps is defined, and possible attachment types are categorized; and 2. the available resources: where various fabrication techniques are discussed, paralleled with a study of various lightweight materials and the applicable construction methods. Possible combinations are then synthesized between materials, fabrication techniques, construction methods, and attachment to the existing fabric. The conclusions form a guideline for design solutions in different European cities.

KEYWORDS: *single occupant-housing, construction methods, lightweight materials, attachment techniques.*

I. INTRODUCTION

With the remarkable population growth combined with the shift of dwelling habits over the past decades, the demand for housing is increasing and its shortage becomes an alarming issue. Over the past 10 years, one-person household has increased by 5% in the EU on average, that accompanied by a decrease of three or more persons households (Eurostat, 2018); meaning that more housing units are required. This shift is outstandingly evident in major European cities due to students and starters influx. These metropolitan regions become overcrowded and housing supply fails to keep up with the increasing demand.

Consequently, prices increase, mainly in the centers due to lack of the land; people find it uneasy to obtain good housing for reasonable prices (Eurostat, 2018) and thus students and starters are pushed to the peripheries of the cities causing urban sprawl. Of course, incorporating smart fabrication techniques and efficient assembly methods using sustainable materials for future houses design would highly alleviate the burden and foster supply-demand keeping up while offering affordable options for starters, yet locating these house in the crowded city centers is nearly impossible due to the high land prices. But what if these houses could exist without land acquisition? Looking at the cities with different eyes allows us to see opportunities in the crowded city centers whether in unused rooftops, blind walls, or even gaps between buildings. The small scale of an optimized one-person house gives the potential to attach to these spaces in the existing fabric. This leads to the following research question: “How to create a design guideline for the smart fabrication and efficient assembly of single-occupant housing, for students and starters, that attaches to the existing fabric of crowded European city centers?”

This question targets the technical section of a wider guideline that extends to include the social aspects of the issue. This guideline is designed to be the backbone of feasible design that response to a real time issue. It is thus composed of 5 main sections: 1. *Choose your city, define targets groups.* 2. *Look into the laws, choose how to react.* 3. *Study the fabric, choose how to intervene.* 4. *Look into the neighborhood define needed programs.* 5. *Study the users, make it a home.*

This research paper goes in depth in part 3 and attempts to find answers in that section. To do so, the results are split into 2 main chapters: 1. *Existing and its potentials:* where a material catalogue of the existing fabric will be presented along with its characteristics, the type of gaps will be defined, and possible attachment types will be categorized. 2. *Available resources:* where various fabrication techniques are discussed, paralleled with a study of various lightweight materials and the applicable construction methods.

II. METHODS

The coming 2 chapters present the results of the conducted research, which was divided into 5 parts. Each step starts with a question that is investigated through appropriate research methods. The results then raise consequent questions that trigger the step after. This research starts with the main research question and culminates in a guideline for design

solutions. This process is illustrated in the diagram below (fig.1). The first aspect to be studied is the existing situation, that was done through background readings about the housing crisis, including statistics that quantify that matter in relation to the cities and groups. This step also involved informal interviews and discussions with from different countries to understand the urgency of the issue from the view of students/starters. Own observations of potentials in crowded cities were also part of this 1st step. This overview led to defining the research further where the focus was put on the existing fabric and the technological advances that could be applied for technical solutions. This triggered the next question: which criteria of this fabric is relevant and what should be taken into account. Through photographic surveys a material catalogue of existing fabric was assembled. These were further studied through literature. Their corresponding construction methods, structural potential, and limitations were the focus for a deeper understanding of the fabric. Photographic surveys, along with observations, also helped in defining criteria to the space which would be considered a potential “gap” for intervention. Attachment styles were categorized accordingly. In the 3rd step, standards of the intervention were given, such as having minimum physical impact on the fabric. For that, 2 aspects: light materials and construction techniques, were studied in detail through literature and innovation news. The selection of lightweight materials is presented through their physical properties, potentials and costs. These are then paralleled with corresponding fabrication techniques, which are studied through case studies and literature in the 4th step. These are analyzed and discussed in relation to the selected materials. Their potential application is discussed in step 5 where possible combinations are analyzed between materials, fabrication techniques, construction methods, and attachment to the existing fabric. The conclusions form a guideline for design solutions in different European cities. **The project could potentially be studied and applied in other metropolitan cities, yet this research is based on the statistics of EU cities and thus would be limited to this scope for the availability of info, constant updates, accessibility of these studies, and the continuous municipal, governmental and organization efforts and initiatives in solving the housing issue which is crucial for the feasibility of this project.*

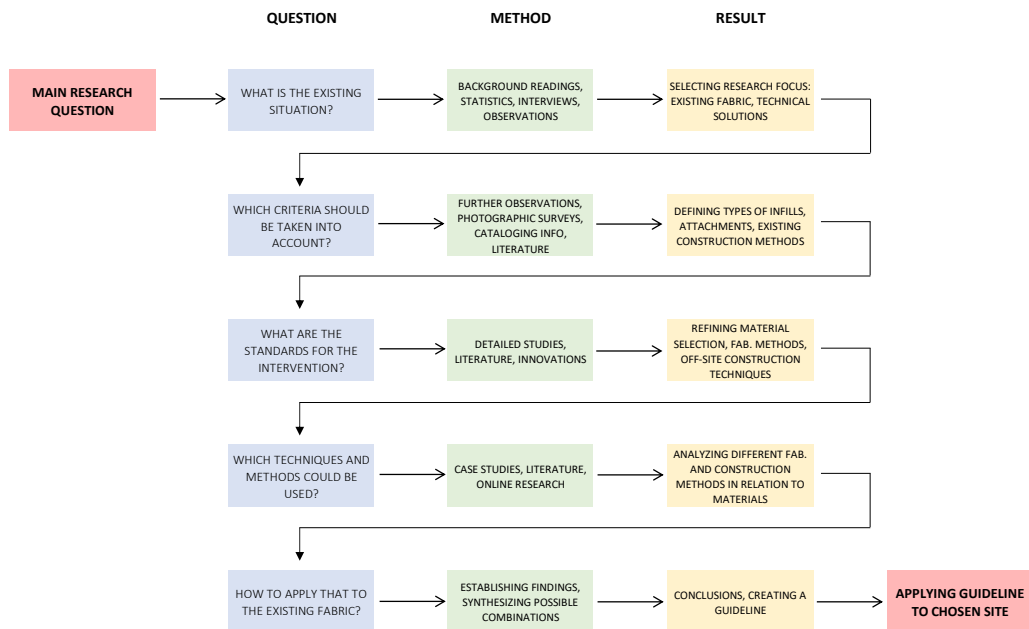


Figure 1. Research methods diagram

III. RESULTS

1. The Existing Fabric and its Potential

The first part of the results gives an overview of the current situation. As the statistics show, housing shortage is highly facilitated by the change in dwelling habits and it is more evident in major cities. Students and starters are the most affected by housing shortage as housing overburden is recorded highest among them. By that they are forced to move out to the peripheries. Through observations and photographic surveys, we can map potential spots: left-over spaces, in the city centers, that could accommodate single occupant housing units which are in increasing demand by the aforementioned target group. The small scale of these units would allow for taking advantage of these

otherwise unused spaces. It also invites for off-site construction by the ease of their transportation. It is crucial for this design to be based on deep technical knowledge of the existing and an open eye for the technological potential to offer feasible solutions for a real-time issue.

1.1. Defining Unused Space:

As the issue is more evident in crowded cities centers, these would form the scope of site observation. Through the photographic survey presented in (fig.2) we can categorize the un-used spaces. These range from vacant rooftops, blind walls, to leftover spaces between two buildings (fig.3). The ‘unused’ space is then defined as the space in crowded centers/neighborhoods which has no prospect of being used otherwise for a common scale building nor for public activities. It is also a space that does not require land acquisition.

As these spaces are intended to be used for housing, it is important to set some criteria for that would correspond to better qualities of dwelling. These criteria are in line with the major requirements of the building regulations for housing in Europe (Visscher and Meijer, 2006:3), namely dimensions of habitable space, daylight, and accessibility. Keeping with the intentions of the project, an extra criterion is added: proximity of the selected gaps.

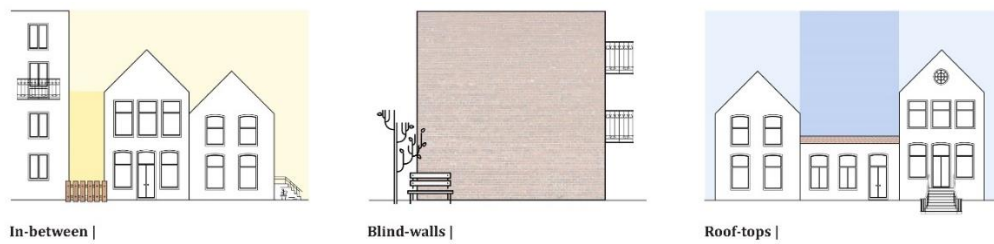


Figure 3. Unused spaces

1.2. Determining Attachment Styles:

Various possibilities of attaching to the unused space are represented in fig.4 below. These possibilities could be categorized as: freestanding, resting on, hanging from, and /or attached to. While hanging and attaching are highly applicable to any of the gap situations, squeezed in, freestanding, and resting are mainly applicable specifically to between buildings, blind walls, and rooftops respectively. Nevertheless, the choice of attachment style highly depends not only on the type of gap but on the structural potentials of the host building.

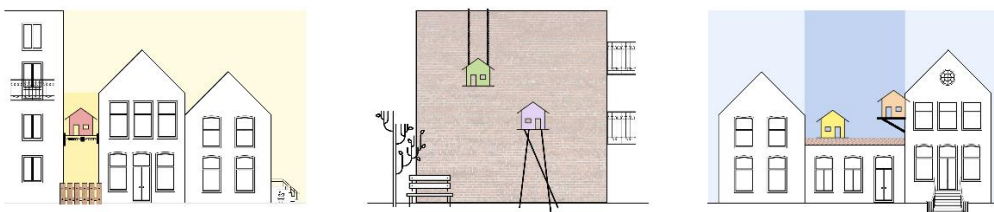


Figure 4. Attachment styles

1.3. Understanding the Existing Fabric:

As the aim is to create a design guideline applicable in various cities, it is important to produce an overview of the existing fabric. A material collage from different European cities is collected (fig.5). The usage of different materials corresponds to different construction methods the understanding of which is crucial for further intervention., For each method the used construction techniques are discussed, the structural capacity of the construction is highlighted for s better understanding of the preferable mode and location of attachment.



Figure 5. Material collage

1.3.1. Brick Construction:

Brick construction, namely unreinforced masonry is commonly found in older centers of Europe. In this construction, the slabs and roof are made of timber and their loads are transferred to the external brick walls and to occasional timber columns on the inside in case of bigger spans. The brick walls are load bearing, they could be laid in different bonds and are connected by mortar. They are occasionally connected to the beams at the slab level with metal ties.

According to Chudley and Greeno (2004:335) the main factors governing the load bearing capacity of the bricks are: *1. Thickness of wall. 2. Strength of bricks used. 3. Type of mortar used. 4. Slenderness ratio of wall or column. 5. Eccentricity of applied load.* These could be determined from the year of construction and through surveys.

Through their bonding bricks work as a whole transferring the loads throughout the wall composition. They work well in compression and have a high capacity for gravitational forces. Yet, recent studies have shown that bricks typically fail in case of lateral loads, such as seismic activities.

In recent years, bricks construction developed to improve thermal comfort and cavity walls were introduced. Here the inner wall is load bearing. The inner construction remains mostly unchanged. Bricks could also be used as cladding; in this case they are only self-bearing. The internal structure could be wood, metal, or concrete.

1.3.2. Stone Construction:

Unlike the historic stone construction that is similar in its logic to the brick construction, where the external walls are made of layers of stone to which the loads of the timber framed roofs and slabs are transferred, the stone buildings we widely encounter in European cities centers use an adjusted technique. The front facades are made of dressed stones which are laid on the top of each other and are load bearing. The last floor of this façade is usually made out of timber. All the backside facades are constructed as a frame structure of either timber or metal. The infill walls are from stone rubble or bricks respectively. The floors are also made of timber elements.

As an evolution, metallic profile beams with plaster infills, replaced the massive timber beams. In some buildings it is possible to witness the usage of both techniques simultaneously. The whole structure is often supported by stone masonry vaults and walls at the basement. Similar to bricks, stones are better in compression than tension, they are also typically stronger than bricks.

1.3.3. Timber Construction:

A lot of traditional timber constructed houses have been lost due to fires hazards along the years, yet some are still preserved. Timber construction has also witnessed a revival in modern times. Timber constructions has evolved from traditional timber members tailor made to fit corresponding members held together with wooden wedges, to using metals connections between factory cut timbers.

Other than the traditional log construction, there are two systems for timber construction: balloon framing where the vertical elements continue from ground floor to roof with intermediate floor suspended from the framework; and platform framing where each story is constructed as a whole, these piled on top of one another from the building. In both cases, the external walls are non-load bearing infills made of wood panels. Outer cladding of wood shingles, or sometimes brick, is common.

1.3.4. Steel Construction:

Another technique is steel frame construction. Here, beams and columns are made of steel channels bolted together. The walls are made of panels with steel channels as structural support lined with plasterboard. The panels are bolted together on site and they are one story high. Often the outer wall is made of self-supporting brickwork connected to the inner panels by metal wall ties.

The main factors governing the load bearing capacity: *1. Size and type of channel, 2. Shape and area of cross section, 3. Connection type, 4. Base plate type.* Metals are generally strong in both tension and compression and the precise characteristics highly depend on the alloy used.

1.3.5. Concrete Frame Construction:

In this construction, the beams, columns, and slabs are made of concrete. Concrete is strong in compression yet weak in tension. It is therefore reinforced by metal rods to increase the tensile resistance of the structural members. They form a frame where the columns are one story high and the beams rest on them. The external walls are made of CMU blocks that are laid in one another to form the infill. These are non-load bearing.

The structural capacity of this construction thus depending on the following factors: *1. Concrete type, 2. Aggregate type and percentage, 3. Members' dimensions/spans, 4. Reinforcement quality, number, diameter, spacing, shape, and type.*

1.3.6. Precast Concrete Construction:

This is a more recent technique that compromises factory produced components of precast concrete. Here, both the partitions and external walls are load bearing, they transfer the vertical loads from the precast prestressed floor panels. The floor provides for later stability. The components are stacked on site with floor panels bearing on the walls. The units are connected by steel ties projection from adjacent panels completed by in situ concrete. External cladding in brick or stone is also possible, these are secured to the precast walls by built-in ties.

The factors governing the load bearing capacity of this construction are: *1. Concrete type, 2. Reinforcement quality, number, diameter, spacing, shape, and type. 3. Type/quality of connecting joints 4. Span*

2. Available Resources:

It is crucial to ensure that the load bearing capacities of the existing buildings allows for the additional proposed units to be attached. For that it is important to keep the units' weight to the minimum. The choice of lightweight materials becomes essential. Moreover, considering the proposed location in crowded cities centers, off-site construction of the unit gains preference. This also encourages the incorporations of effective digital fabrication techniques and smart construction methods. It is also important to propose efficient connecting methods to the host buildings that distribute the weight in a smart and safe manner.

2.1. Lightweight Materials:

2.1.1. Wood:

Timber has a low weight to strength ratio which means that it has a high structural efficiency as carried load per unit weight is high. Of course, the unique properties would depend on the wood species and the type of timber products, which are many and could be classified into natural solid timber and engineered timber products (Ramage et al, 2017). The access to this variety of techniques and methods allows for a wide range of options providing diversity depending on design requirements. Natural solid timbers are considered more sustainable as they require fewer processing steps. They are also easier to reuse or recycle as they only contain natural timber elements. Furthermore, the availability of timber in most parts of the world makes it a sustainable and affordable construction material. Yet timber is prone to decay, fungi, and insect infestation if not treated and maintained properly.

2.1.2. Metals:

Metals, existing in different types and alloys with unique qualities, also generally have a low weight to strength ratio. They are considered the strongest architectural materials (Bell and Rand, 2014: 129). Metals can be sorted into ferrous metals that contains iron, such as steel, these are generally stronger, and non-ferrous metals which do not contain iron, such as aluminum, these are more malleable. Metals can be mixed to form new types with controlled optimum qualities for a particular architectural application. Production of metals requires a lot of energy. Nevertheless, metals can be recovered and reformed making them relatively easy to reuse and recycle. Metals are also durable materials, yet they should be maintained to delay corrosion of ferrous metals and well-treated to protect from fire hazards in case used for structural purposes.

2.1.3. Plastics:

Plastics are lightweight materials with a typically high strength to weight ratio. Their structural properties have been highly improved due to enormous advances in plastic technologies. Generally, plastics are highly malleable and can be shaped into limitless forms, even inflatables such as ETFE. They can be defined in 2 types, thermoplastics that can be modeled with high temperatures, and thermosetting plastics which are more complex and rigid, these are stronger but cannot be reformed by reheating. Plastics come in various colors and diverse properties. Being a man-made material, there is a constant improvement in their characteristics. This allows for a diversity of design applications. Plastics are synthetic and made of oil, thus their production is not sustainable. Yet, thermoplastics can be molded with heat while retaining their original properties and are thus reusable and recyclable. Nevertheless, plastics are low cost materials which makes them popular. They also have excellent corrosion resistance and are less affected by water and decay. On the other hand, compared to other construction materials are not stiff, and the surfaces are brittle if unprotected. This is being improved in the plastic industry. Bio-based plastics are also being developed.

2.1.4. Fabrics:

Tensioned fabric structures are another example of high applied loads to weight ratio. Great advances have been made in this field in the past years. A wide variety of fabrics is now available, the behavior of which can be analyzed by advanced software, which allows for interesting form finding methods. The fabric is typically supported by lightweight tensile cables and rigid supports. The choice of materials, the fibers and the coating, and the weaving technique, gives the fabric its characteristics and determine its resistance to decay. Fibers range in transparency reaching 95%. Being of high tensile forces the fabric could be used as tensed roofs or inflated façade cushions. As the fiber for coating are mainly made of plastics, fabrics are not very sustainable. Yet, their applications require very minimal amount of materials compared to other solutions. Fabrics are also relatively low cost with a 10 to 30 years lifespan, for deplorable structure a shorter lifespan is expected.

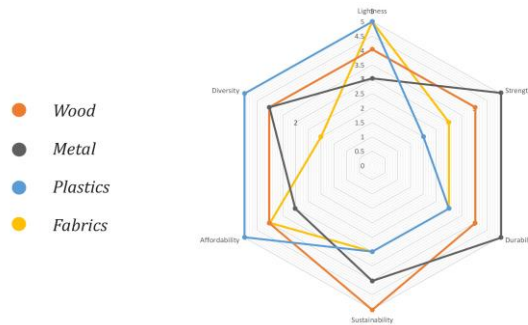


Figure 6. Lightweight materials characteristics

3. Case studies

The lightness of an object is not limited to the choice of lightweight materials only. It highly depends on the shape they are given and the function that these materials would perform. As van Hinte emphasizes in his book on lightness, there must be compatibility between shape, function, and material properties. Careful composition of materials minimizes redundancy in usage, as such that reduces the weight. Furthermore, the choice of structure plays a major role. Tension is always favorable in this context as putting materials in compression requires thickness thus adding weight to the structure (van Hinte, 2005:31).

To gain a better understanding of these notions a matrix was made with a selection of projects under 8 headlines. The full matrix is included in the appendix.

As attaching the proposed structures to an existing building in a safe manner and with the least harm to the host is a challenge, in this paper two headlines will be further discussed, namely lightness (a) and attachment (b).

The following description focuses on how these examples deal with either or both. These examples do not only represent potential solutions but also highlight some problems to be considered.

Ski Haus, Richard Horden, Switzerland, 1991

This shelter house is enclosed with carbon fiber, a hardly sustainable and expensive material. In this example tension is not the main structural force yet the total weight of only 315kg is impressive. The aluminum frame used for the structure plays an important role not only for its lightness of 120kg (a) but also for the compatibility of its properties with the given weather, as aluminum gains strength in lower temperatures. The joints were carefully designed for strength and extra safety. The legs can be folded to adapt to ground and transportation conditions and each have a triangular base that minimizes disturbance on site. (b)

~ Aluminum is a lightweight structural option for a small-scale construction. Joints play an important role. Chosen materials must be cost-efficient and sustainable.

Plas-2-Point House, Marcel Bruer, USA, 1943 (unbuilt)

The structure of this house was inspired by the airplane design. Roof and walls cantilevered from central girders. The wall panels therefore are non-supporting they act as tension members only. By this system, the structural elements are reduced to 2 girders and 2 columns (a). This results in a 6-room house that weights around 3-4 tons, one third the weight of a standard house of this size. The anchorage of the house is also an interesting feature as it is mounted on only 2 foundation blocks which facilitates assembly and reduces impact on site. (b)

*~ Tension of girders reduces the need for many structural elements
Minimizing foundation elements reduces length of assembly on site.*

Wichita House, Buckminster Fuller, USA, 1944

The Wichita house also manages in reducing the weight to 3 tons, this time for a bigger area. Everything including the livable load of 120 people was suspended from the 6.7m high central mast of 32kg, with crisscrossed steel tension cables and compression rings. (a) The house is set on a single foundation. Stairs were also used to further stabilize the house. A team of 6 people were estimated to assemble the house in 1 day. (b) Aluminum sheets were used for floors and roof, they had low insulation properties and were reported to make sounds as the temperatures change.

~ Tension from a mast is the lightest option yet further elements might be needed to stabilize the structure

Homed, FramLab, NYC, USA, 2016

This project takes advantage of “vertical lots”, the blank sidewalls. It works as a plug-in system where the structural framework is made up of modified scaffolding - an economical, flexible system that quickly can be erected and disassembled. (b) It leaves minimal trace on the host building. It also allows for diversity of the plugged-in units.

~ Scaffolding is as an inspiration for an economical and flexible system. Joint modifications might be required

Rucksack House, Stefan Eberstadt, Germany, 2004

This 9m² unit is attached to the host by means of steel cables and metal anchors that go through the façade. (b) The anchors are a subversive construction, yet the cables provide stability with the least materials. The cables are also adjustable in length and connection according to the type of host building. The suspension process is rather complex. (5-6 hours with the façade being previously prepared)

~ Cables are a flexible and light solution while the anchors cause damage to the host building and introduce cold bridges. Including the anchorage system within the unit structure might complicate the attachment process that requires more intricate on-site work.

Micro Compact Home, Horden Cherry Lee Architects, Munich, Germany, 2005

This house was fabricated and assembled completely off-site. The aluminum subframe was preassembled on site in parallel with the process in the factory, 3cm pins on the frame acted as anchor points on which the house is inserted. The process of the unit installation took only 5 minutes with the help of a crane. The subframe was provided with adjustable micro piles that adapt to and reduce impact on the site. (b) The unit is constructed with a timber frame system and aluminum cladding; it weighs 2.2 tons. A reduction of 20% of the weight in prototypes constructed with an aluminum frame instead. (a) 3.5 cm vacuum insulation used within the roof to minimize weight (eq. to 10cm of polyurethane foam) (a)

~ Detaching the house unit from the frame allows for it to be combined in various clusters when provided with the appropriate sub-structure.

Pin connections can be used to attach the unit to the subframe

Timber can be substituted by aluminum frame for lighter units

Vacuum can be used as a lighter and thinner insulation layer

Aluminum can be used as a cladding material with extra layers in the façade panel for insulation and security

4. Design Strategies:

The analysis of the projects of the previous matrix allowed for creating a list of measurable characteristics upon which the technical aspects of the selected projects were compared to other possibilities and scored. Strength and weaknesses of each were then highlighted to conclude to technical design guidelines on how to connect units to existing buildings.

In the lightness section, 3 structures: suspension from a singular mast, girder system with suspended walls, and the aluminum frame, system proved to be the most successful. For attachment, modified scaffolding, detaching the base from the unit, and cables offered interesting solutions.

A selection of design solutions offered by these options are summarized below:

lightness

suspending loads from a mast with crisscrossed tension cables and compression frame

minimizing number of structural elements' number and size by favoring tension over compression

using materials of high strength to weight ratio (aluminum, steel, wood)

structural stability

a light frame must be braced for rigidity

triangulated tension cables provide a light and strong bracing option

extra elements could be used to further stabilize the structure, such as an external staircase

adaptability to different attachment types

detaching the house unit from the frame allows for various combinations
modified scaffolding with firm joints is a flexible and cost-efficient solution
creating a kit of part system that can adapt to different sizes of gaps
adjustable legs

affordability

light weight construction minimizes the amount of materials needed
modularity of elements reduces production costs
using available resources and minimizing custom made elements

difficulty of assembly

minimum number of foundation elements
efficient joints that combine to several structural elements at once
reversible joints between unit and frame

impact on host building

lightweight addition
attachment system must distribute the weight evenly to the load bearing structure
light triangular bases and scaffolding inspired anchors touch the building lightly
cables are a flexible and light solution for extra support
carrying the loads to the street or roof tops whenever possible

façade flexibility

structural frame with infill wall construction
modularity of façade units enables interchangeability
wall panels suspended from central girders are non-supporting they act as tension members only and thus could be
of variable designs, openings, or could even be eliminated where desired
introducing columns reduces the need of bracing on the façade

IV. CONCLUSIONS

The understanding of the existing fabric's structure gives insights to the acceptable modes of attachment, summarized in fig.7. In the case of brick construction, as the walls are structural but considerably weak when exposed to lateral forces, attaching to the roof structure becomes a viable option, as the loads are then transformed to the walls in form of compressive forces. The hanging technique can be then applied through force transforming mechanisms such as pulleys. If the forces are applied on the wall itself, they should be preferably connected to the beams for lateral force distribution. In addition, any force applied directly to the wall should be well distributed on a wide surface area. Compressing the proposed units in between such buildings is also possible. Similar recommendations apply to the structural stone façades. For the back-walls of this construction, and all the other framing methods (timber, insitu concrete, and metal) where the infill walls are non-structural, the attachment should happen at the level of structural members, i.e the columns and beams. This puts restrictions on the location of the attachment. Both timber and metal are strong in both directions and would be able to handle compressive and lateral forces with adequate calculations. Thus, attaching to or hanging from these structures is possible. In case of concrete columns, it is better to put the loads on roof members that are adequately reinforced for these types of forces and would transfer them into the columns in preferable form of compression. Lateral forces are possible on the level of the beams. Compressing between such buildings is possible but attention should be then paid to resolve the alignment of the beams of the 2 adjacent host buildings. While the possibility of single attachment to concrete frame remains at a border line to be determined by adequate calculations in the design phases. In comparison, precast concrete could be more suitable to attach to since the walls are structural which puts no restriction on the location of the attachment. Compressive forces, i.e hanging, are still preferable. Applicable for all the constructed fabric remains the compression between 2 buildings as it distributes the forces more evenly. For horizontal roof tops, units can be attached as long as their weight falls on the structural members. A space frame that distributes this load is a possibility. Distribution of forces could also be done by the use of pulleys and/or by combining techniques. For example, the lateral forces exerted by an attached unit could be minimized by increasing the surface area which could be done by transferring loads to a second wall, or by supporting the unit with tension cables connected to the roof structure that transfers part of the loads into compression. If possible, scaffolding like structures or structural poles could be used to hold the major weight of the added unit, the attachment to the host facade would be minimal to ensure lateral stability.

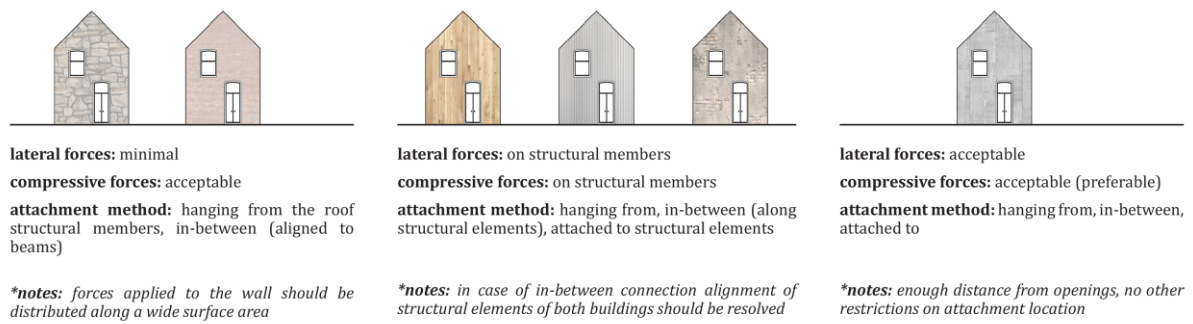


Figure 7. Allowable forces and attachment techniques per host type

Furthermore, to ensure that the host building is capable to handle the structural loads, the choice of attachment technique is of utmost importance and reduction of the weight of the attached unit is a necessity. For attachment, modified scaffolding, detaching the base from the unit, and cables offered interesting solutions. According to the case studies' analysis, detaching the attachment base from the unit proves to be more cost efficient than providing each unit with adjustable legs. That allows for various combinations, as a kit of parts system. The mix and match offer adaptable solutions to various gaps sizes and types. Inspiration could be taken from scaffolding system, a cost efficient, available, and flexible solution for low impact attachment and efficient weight distribution on the hosting building. The scaffolding tubes come in various dimensions, yet the nodes are to be modified for better structural performance and less space occupancy. Bracing of the scaffolding system could be also rethought by the usage of steel cables.

Due to space restrictions in the proposed sites on-site work is to be kept to the minimum, off-site assembly is then preferable. The small size of the units allows for the ease of transportation to site. Detaching the base also allows for faster on-site assembly of the unit. Minimal connection points with reversible joints, such as ball mechanism, twist and lock mechanism, and slide and lock mechanism, are main solutions for ease of connection and disassembly. That is to allow units to be entirely removed or replaced when necessary.

The lightness of the unit is achieved by both the usage of lightweight material and their smart application in an efficient structural system that requires minimum structural members for stability.

From the comparison of the various structural systems the 3 structures: suspension from a singular mast, girder system with suspended walls, and the aluminum frame, system proved to be the most successful. The chart below represents the scoring of each on different criteria. This shows that while an aluminum frame system scores well on all the criteria, the three projects complement one another. A hybrid structural system could thus achieve better results in structural efficiency and façade flexibility, yet it might prove to be more complex. This would require further design explorations taking into account the small size of the unit to find a balance between efficiency, complexity, and costs.

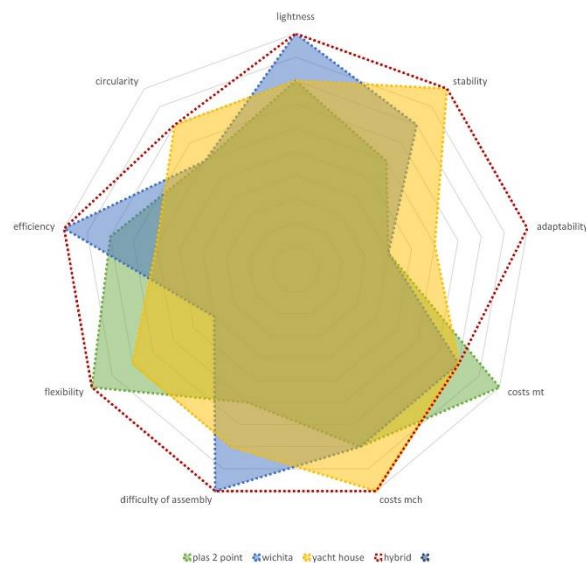


Figure 8. Lightweight materials characteristics and applications

As for the materiality of the unit itself, the selected material palette includes strong yet light materials, their choice would highly depend on the desirable physical and aesthetic results on a given site. Timber and ferrous metals are ideal for structural purposes. Aluminum also proves to be a good solution for small scale structures. Thinner wood plates are also highly suitable for rigid internal partitions. Non-ferrous metals on the other hand could be used as facade finishes as they are available in various shades and finishes and not prone to corrosion, yet sufficient insulation must be provided. Tensed fabrics are mostly useful for bigger spans, which is not very relevant in relation to the proposed scale of the houses. Yet, due to their extreme lightness and tensile strength they are adequate in case of suspension. They could also be potentially used for the facade given that the needed insulation properties can be achieved. Using fabrics as partitions is also an option. The integration of fabrics in the design could highly contribute to a lighter unit. As for plastics, only recyclable options should be considered. These are suitable for more organic forms as they are easily molded. They could also provide enough transparency with integrated sun screening solutions and thus could be used as a lighter alternative to glass. Structurally plastics need a lot of mass to reach good performance, which eliminates this option for the purpose of this project. Inflatable plastics can provide solutions, yet they require more maintenance to ensure structural stability, they are more expansive than other solutions, and the spaces created are not as efficient. For that plastics will not be considered for structural application in this project.

• Characteristics:

| | lightness | strength | durability | sustainability | affordability | diversity |
|----------|-----------|----------|------------|----------------|---------------|-----------|
| wood | 4 | 4 | 4 | 5 | 4 | 4 |
| metal | 3 | 5 | 5 | 4 | 3 | 4 |
| plastics | 5 | 2 | 3 | 3 | 5 | 5 |
| fabrics | 5 | 3 | 3 | 3 | 4 | 2 |

• Applications:



Figure 9. Lightweight materials characteristics and applications

The research provides the guideline for first design choices of attachment, structure, and material selection for the proposed lightweight intervention, included in the appendix. Yet, as the exact site is chosen it is essential to conduct necessary surveys and calculations on the existing buildings as their current state would highly affect their structural load bearing capacity. This would also help determine the maximum allowable weight of the unit to be designed. Of course, the goal is always to achieve the lightest solutions, yet some situations might require more complexity and are thus less cost efficient. For that it is important to determine what is necessary. Taking climate into consideration also affects the choice of materials beyond their weight and appearance. The minimum thickness of the walls is also another consideration to be taken into account, not only for the weight but also due to space restrictions and the need to provide the maximum usable area in each unit. These issues should be further tackled in the design phase. As for the building technology aspect, the attachment styles here provided do not yet offer viable solutions for avoiding thermal bridging, which should be also addressed in the design phase as compromising the quality of the host buildings is not an option.

REFERENCES

Agarwal K., (2019). *Hybrid Timber Construction Technology*. Delft: TU Delft.

Bell, V. B. and Rand, P. (2014) *Materials for design 2*. First edn. New York, New York: Princeton Architectural Press.

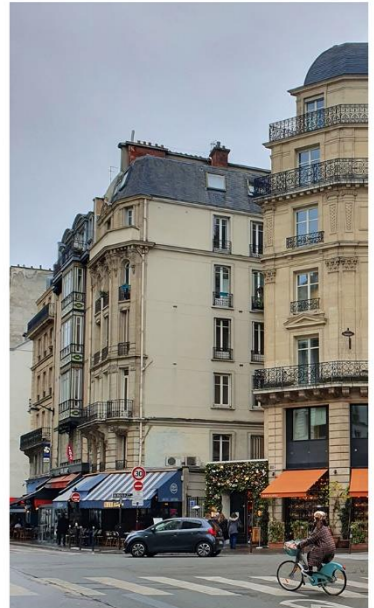
Berger, H. (1996) *Light structures, structures of light: the art and engineering of tensile architecture*. Basel: Birkhäuser.

Beukers, A., Hinte, E. van and Vincent, J. (2005) *Lightness: the inevitable renaissance of minimum energy structures*

Boothby, T. E. (2015) *Engineering iron and stone: understanding structural analysis and design methods of the late 19th century*. Reston, Virginia: ASCE Press/American Society of Civil Engineers.

Brookes, A. and Poole, D. (2004) *Innovation in architecture*. London: Spon Press.

- Cardoso R., Paiva A., Pinto J., Lanzinha J. C. (2019). Structural and Material Characterization of a Haussmann Building Complex at La Madeleine, Paris. In: *Wseas Transactions on Environment and Development*, volume 15. Covilhã: Trás-os-Montes e Alto Douro University.
- Champion, S. *et al.* (1996) *Access scaffolding*. Harlow: Longman and Chartered Institute of Building.
- Chudley R., Greeno R. (2004) *Building construction handbook*. 5th edn. Oxford: Elsevier Butterworth-Heinemann.
- Dangel, U. (2017). *Turning point in timber construction*. Germany: Birkhäuser .
- Engelsmann, S., Spalding, V., Peters, S. and Stein, R. (2010) *Plastics: in architecture and construction*. Basel: Birkhauser.
- Gijzen, R.P.T., (2017). *Modular Cross-laminated Timber Buildings*. Delft: TU Delft.
- Groat L. N., and Wang D. (2002). *Architectural research methods*. New York: J. Wiley.
- Horden, R. and Blaser, W. (1995) *Light tech: towards a light architecture = ausblick auf eine leichte architektur*. Basel: Birkhäuser Verlag.
- Horden, R. (2008) *Micro architecture: lightweight, mobile, and ecological buildings for the future*. London: Thames & Hudson.
- Jodidio, P. (2007) *100 great extensions & renovations: 100 extensions et rénovations remarquables*. 1st edn. Mulgrave, Vic.: Images.
- Lucas R. (2016). *Research methods for architecture*. London: Laurence King Publishing.
- Melis, L., Bestebreurtje, M. and Haan, A. de (2003) *Parasite paradise : pleidooi voor tijdelijke architectuur en flexibele stedenbouw*. Rotterdam: NAI Uitgevers.
- Neriduet S., Dilip Kumar Pasupuletib V., Dongreaa A. (2017). Impact on Structural Behavior due to Installation of Billboards. In: *Jurnal Teknologi (Sciences & Engineering)*. Telangana: Vidya Jyothi Institute of Technology.
- Oñate E, Kröplin Bern and International Conference on Textile Composites and Inflatable Structures (2005). *Textile composites and inflatable structures*. Dordrecht: Springer (Computational methods in applied sciences, v. 3).
- Richardson, P. (2009) *XS extreme: big ideas, small buildings*. London: Thames & Hudson.
- Salomon, S. and Valdez, N. (2006) *Little house on a small planet: simple homes, cozy retreats, and energy efficient possibilities*. Guildford: Lyons Press.
- Schittich, C. and Institut für Internationale Architektur-Dokumentation (2010) *In detail: small structures: compact dwellings, temporary structures, room modules*. Basel: Birkhäuser.
- Structural Engineering Institute. Task Committee on Tensioned Fabric Structures (2013). *Tensile fabric structures: analysis, design, and construction*. Edited by C. G. Huntington. Reston, Virginia: American Society of Civil Engineers.
- Visscher H., Meijer F. (2006). Workshop 19 - Legal Aspects of Housing, Land and Planning Building regulation for housing quality in Europe. In: *ENHR conference "Housing in an expanding Europe: theory, policy, participation and implementation"*. Ljubljana



1.

Project Settings

1.1. Location

which are the potential cities where these single-occupant units would make a difference?

- Criteria for choosing the city:

1. urgency of the housing issue:

- cities where single-occupant housing is in demand
- cities where it is uneasy to find affordable housing
- cities where the percentage of owning is low
 - * which implies housing overburden and/or transient users
- a high percentage of students and/or starters

2. initiatives:

- governmental/municipal efforts to resolve housing issues:
 - modifying planning regulations
 - simplifying building processes
 - offering fundings
 - carrying surveys
- NGOs and housing/social organizations' initiatives
 - conducting surveys on users' needs
 - forming statistics on city demographics
 - raising public awareness on housing issues
 - promoting sharing, exhibiting successful examples
 - translating public needs to municipalities
 - finding funding solutions

3. city character:

- acceptance of experimental approaches
- a need/willingness to change
- positive responses to provocations
- samples of innovative/controversial projects
- sense of community
- availability of "gaps" in proximity

* there should be a balance between the urgency and potentials

- List of potential cities:
Copenhagen, Vienna, Paris, Delft, Hamburg, Stockholm, Zurich, Amsterdam, Munich, Helsinki

1.2. Target group

who are the future users of the proposed housing units?

- Housing overburden is mostly evident in ages 15-29
- Young generations are willing to change/experiment



- Choice of one of the categories or both depends on:
 - the percentage of each in the chosen city
 - successful housing initiatives if any - is the student housing already enough to provide for students?

* it is important to understand what these groups really want

2.

Regulations and Laws

2.1. Building regulations

how to find relevant laws? what to look at and where?



- Existing relevant laws:
 - Air rights, NYC - *unused space rights*
 - La Loi Alur, Paris - *lot acquisition*



- Municipal archives and governmental websites:
 - laws on land acquisition/rent
 - laws on co-owned housing
 - laws on house extensions/ additions
 - laws on temporary construction
 - laws on roof additions and modifications
 - laws on balcony and 2nd facade additions
 - laws on public and green spaces

2.2. Responding to laws

how to react to these regulations ?



- Follow the laws - *abide by extension, land acquisition, and building permits rules*

case study: - *the 3Box, Paris*
- *Didden Village, Rotterdam*



- Find loopholes - *use existing rules meant for one purpose and tweak the design to meet the regulations of that*

case study: - *the H-VAC, London*



- Break rules - *through provocative temporary designs*

case study: - *Manifest destiny, San Francisco*

2.3. Fundings

who could fund the construction of the housing units?



- Student housing organizations
- Governmental subsidies
- Neighborhood tenants - *public space and renovation purposes*

* consider : *land/ownership issues, benefits for the neighborhood, public areas vs. rentable areas*

3.

Resources Study

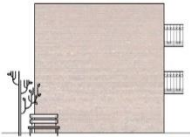
3.1. Unused spaces

what can be considered as "unused space"?

- Types of unused space:



in-between buildings



blind walls



vacant roof tops



- Main considerations:
 - minimum dimensions / area of habitable space
 - enough outer diameter for daylight
 - accessibility
 - availability of potential adjacent structural support
 - proximity of available gaps - forming a neighborhood



- Further considerations - filling the gaps:
 - **not compromising the comfort of existing buildings:**
 - ▶ not blocking daylight/sunlight
 - ▶ not blocking views
 - ▶ not interfering with access
 - ▶ not compromising functional public areas

3.2. Attachment style

how could the units be attached to the unused spaces ?

- Possible attachment types:



compressed



hanging, free-standing



resting-on, attached to



- Considerations:
 - type of unused space
 - structural capacity of the hosting building(s) :
 - ▶ attach to the strongest host
 - ▶ choose simplest/most efficient attachment style
 - ▶ divide the load when possible

3.3. Existing fabric - commonly found construction methods



| structure | ex. walls | *notes | load bearing capacity determined by: | compressive forces | lateral forces | acceptable attachment style |
|-----------|--|--|--|---|----------------------------|---|
| brick | brick, structural | *bricks are stronger in compression, roof loads are transferred to walls, occasional metal wall ties | wall thickness, brick strength, mortar type, bond style | acceptable | minimal | hanging from roof's structural members, in-between (aligned to beams) * forces applied to the wall should be distributed along a wide surface area |
| stone | stone, structural (front facade) rubble infill, non-structural (rest) | *stones are stronger in compression, last floor and roof commonly made of timber | wall thickness | acceptable (on structural wall/members) | | |
| timber | wood infill, non-structural | * wall cladding out of wood shingles or bricks is common | construction type (balloon vs. platform framing), wood type/size | on structural members | | hanging from, in-between (along structural elements), attached-to (structural elements) * in case of in-between connection alignment of structural elements of both buildings should be resolved |
| metal | framed panels, load-bearing | * wall cladding out of bricks is common | metal alloy, size of channel, beam cross section type, connection type | acceptable (preferable) | acceptable (at slab level) | |
| concrete | CMU infill, non-structural | * concrete is strong in compression yet weak in tension, reinforced with metal bars | concrete mixture, elements size, reinforcement quality and dimensions | acceptable (preferable) | acceptable | hanging from, in-between, attached to * enough distance from openings, no other restrictions on attachment location |
| | precast concrete units | * slab loads are transferred to the walls, reinforced with metal bars, connected with steel and concrete | concrete mixture, reinforcement, connecting joints' quality, spans | acceptable (preferable) | acceptable | |

3.4. Lightweight materials

what are the available materials and where is their optimal application?

- Characteristics:

| | lightness | strength | durability | sustainability | affordability | diversity |
|----------|-----------|----------|------------|----------------|---------------|-----------|
| wood | 4 | 4 | 4 | 5 | 4 | 4 |
| metal | 3 | 5 | 5 | 4 | 3 | 4 |
| plastics | 5 | 2 | 3 | 3 | 5 | 5 |
| fabrics | 5 | 3 | 3 | 3 | 4 | 2 |

- Applications:



strength:
• wood
• metal (ferrous)



strength, lightness:
• wood



lightness:
• wood
• plastics
• fabrics



durability, diversity:
• metal sheets (non-ferrous)
• treated wood
• plastics



lightness:
• wood
• plastics (reinforced)
• tensed fabrics



transparency:
• plastics (inflatables)



- Goals:
 - lightweight unit
 - structural stability
 - good thermal performance
 - maximized usable area - thin elements

3.5. Fabrication methods

which fabrication methods could be used for time/cost efficiency?

| | -LASER | -WATER | -PLASMA | MILLING | NIBBLING | PUNCHING | 3-D PRINTING |
|--------------------|-----------------------|--|----------------------------|--|---------------------------------------|---------------------------------------|---|
| MATERIALS | Almost all materials | Rubber Plastic Textiles Paper | Conductive & raw materials | Wood Foam Cardboard (aluminium) | Steel Brass Aluminium Copper | Steel Brass Aluminium Copper | 'Structural link' Concrete Mud Plastic |
| MATERIAL THICKNESS | 400 mm | Up to 350 mm | 3000 mm | Up to approx. 250 mm (with 100 mm drill) | Up to 8 mm | Up to 8 mm | Variable to materials and machinery |
| SIZE SEAM | 0.1 - 0.5 mm | 0.1 - 0.25 mm | 0.8 - 1.5 mm | 1 mm dependent on the milling head | 0 to 5 mm | 0 to 3 mm | Not applicable |
| SPEED | 300 m/min | 35 m/min | 6 m/min | Approx. 10 m/min | 1200-2800 strokes/min | 1400 strokes/min | Variable to both machinery and materials |
| FINISHING NEEDED? | Dependent on material | Dependent on material | Yes, grinding | Yes, grinding | Yes, grinding the edges | Yes, grinding the edges | Usually not |
| GEOMETRY OPTIONS | 2-D | 2-D | 2-D | 3-D | 2-D | 2-D | 3-D |
| ENERGY CONSUMPTION | 100 kW | 37 kW dependent on pump | Approx. 80 A | 18 kW | 25-50 kW | 25-50 kW | Variable to both machinery and materials |

Digital fabrication techniques (Remmerswaal, 2015:33)

3.6. Connecting techniques

which existing temporary connection methods could be used permanently for each attachment method?



construction:
• the unit is constructed off-site and transported to the chosen location



unit-structure connection:
reversible lock mechanism
* chosen acc. to main forces/direction



free-standing:
• scaffolding
• monopoles (billboards)
* stable ground foundations



compressed:
• construction support poles
* sufficient side friction



hanging from:
• facade lift mechanism
• pulleys (force transfer)
* minimum distance from the edge

4.

Design Strategies

4.1. Solutions

what are the design strategies derived from the case studies that offer solutions for attaching the proposed units?

- **lightness**
 - suspending loads from a mast with crisscrossed tension cables and compression frame
 - minimizing number of structural elements' number and size by favoring tension over compression
 - using materials of high strength to weight ratio (aluminum, steel, wood)
- **structural stability**
 - a light frame must be braced for rigidity
 - triangulated tension cables provide a light and strong bracing option
 - extra elements could be used to further stabilize the structure, such as an external staircase
- **adaptability to different attachment types**
 - detaching the house unit from the frame allows for various combinations
 - modified scaffolding with firm joints is a flexible and cost-efficient solution
 - creating a kit of part system that can adapt to different sizes of gaps
 - adjustable legs
- **affordability**
 - light weight construction minimizes the amount of materials needed
 - modularity of elements reduces production costs
 - using available resources and minimizing custom made elements
- **difficulty of assembly**
 - minimum number of foundation elements
 - efficient joints that combine to several structural elements at once
 - reversible joints between unit and frame
- **impact on host building**
 - lightweight addition
 - attachment system must distribute the weight evenly to the load bearing structure
 - light triangular bases and scaffolding inspired anchors touch the building lightly
 - cables are a flexible and light solution for extra support
 - carrying the loads to the street or roof tops whenever possible
- **façade flexibility**
 - structural frame with infill wall construction
 - modularity of façade units enables interchangeability
 - wall panels suspended from central girders are non-supporting they act as tension members only and thus could be of variable designs, openings, or could even be eliminated where desired
 - introducing columns reduces the need of bracing on the facade

5.

Neighborhood Analysis

5.1. Program

which functions are available/needed in the chosen neighborhood?



1. study the existing program on site
2. categorize the existing functions and their areas
3. define public areas present
4. conclude which functions are missing/needed

5.2. Character

what characterizes the chosen neighborhood?



- **Privacy levels:**
 - windows: *size, curtains, glass clarity*
 - entrances: *elevation, exposure vs. seclusion*
 - connections to streets: *gradual, abrupt*
 - thresholds between public and private zones: *benches, sidewalks, plants*
 - shared spaces: *purpose, availability, usage*



- **Tenants' demographics**



- **Community sense:**
 - meetings
 - organizations
 - shared properties/projects
 - people's interaction



- **Acceptance level:**
 - public awareness
 - willingness to change
 - shared spaces operation
 - experimental buildings on site



- **Physical conditions:**
 - available amenities
 - required renovation works

5.3. Intervention

what are the further considerations prior to intervention?



- **Considerations:**
 - climate and orientation
 - aesthetic impression - *standing out vs. merging*
 - parasitic level - *degree of reliance on host building*
 - privacy level - *openness vs. seclusion*
 - unit accessibility - *location, retractability*
 - inducing interaction - *case studies:*
Moriyama house, Tokyo ; Cube houses, Rotterdam

6.

Personalization

6.1. Space use

how to personalize the unit according to users' daily space usage patterns?



1. analyze users' needs - *questionnaires*
2. determine required private functions
3. specify the areas of chosen functions
4. define their relation/configuration - *mapping*

**sample studies: praxeology, Frankfurt kitchen studies, "Die Neue Wohnung" - Taut*

6.2. Flexibility

which aspects could require flexibility in the units?



**flexibility in these aspects can be provided by smart changeable elements applied in both private and shared spaces in accordance with users/neighborhood needs*

6.3. Shared (public) space

what would be shared and to what extend?



- choosing which functions to share - *in accordance with recent surveys of future target group*
sample study: ONE SHARED HOUSE 2030 surveys
- considering neighborhood needs - *gardens, kitchens, event spaces, study halls ; renovation works, profit*
- choosing extend of sharing - *facility operation hours, facility management, opening to tenants vs. to public*



- **Goals:**
 - creating/activating a neighborhood
 - encouraging a new way of dwelling - *through sharing, indoor and outdoor relation, and neighborhood engagement*
 - offering cheaper housing - *smaller private rented area vs. larger communal spaces*

6.4. Diversity

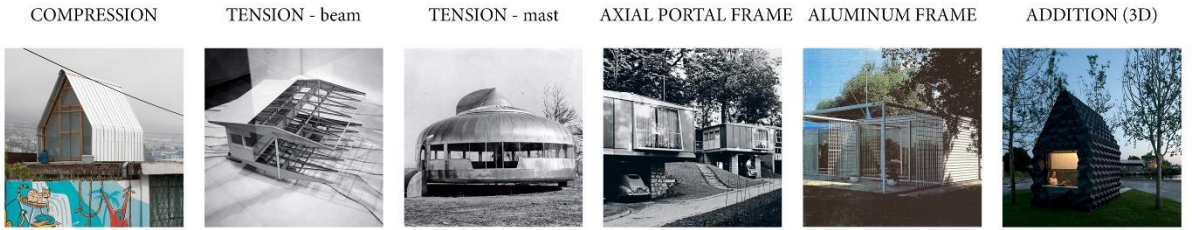
how to achieve the desired level of diversity?

- **Diversity elements :**

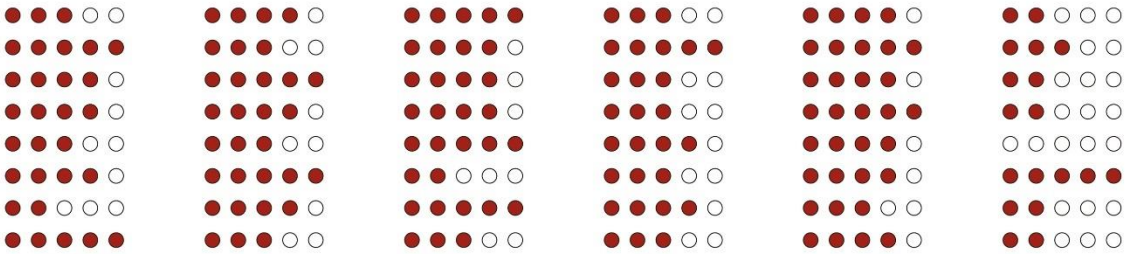


- **Considerations:**
 - desired aesthetic impression - *considering existing buildings*
 - outer vs. inner diversity
 - needed level of diversity - *according to target group*

LIGHTNESS



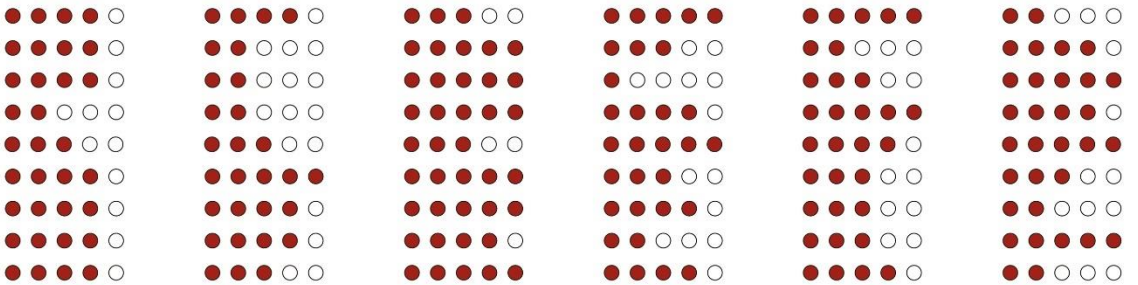
- weight
- structural stability
- material costs
- machinery costs
- difficulty of assembly
- flexibility (facade)
- structural efficiency
- circularity/sustainability



ATTACHMENT



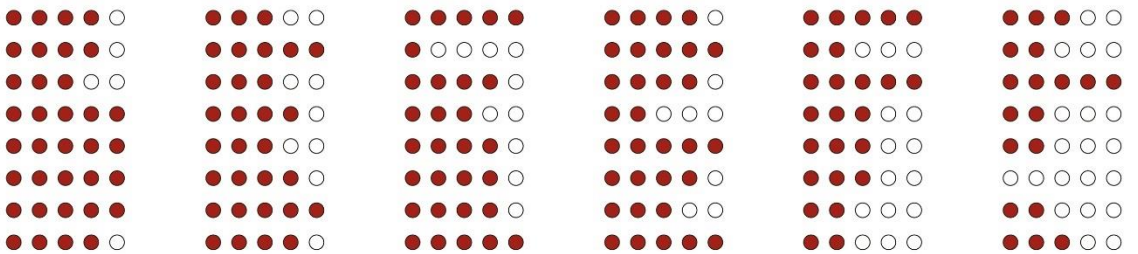
- stability
- demountability, reuse on another host
- impact on host building
- adaptability to different attachment types
- lightness
- material costs
- machinery costs
- difficulty of attachment to host
- circularity



FACADE



- lightness
- efficiency, insulation
- diversity
- material costs
- machinery costs
- attachment difficulty
- circularity/sustainability
- durability

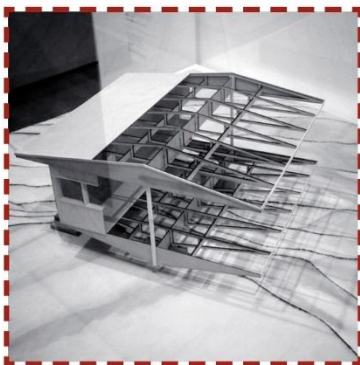
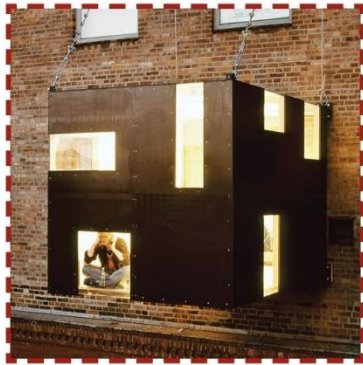


LIGHTNESS

ATTACHMENT

SCALE

ASSEMBLY

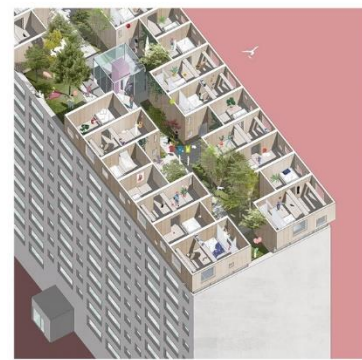
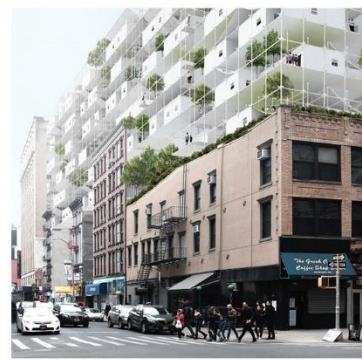
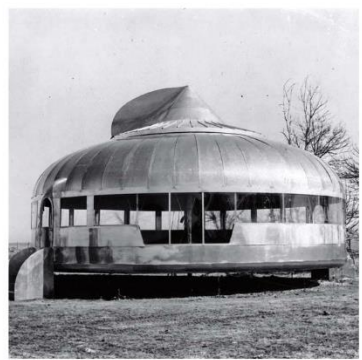
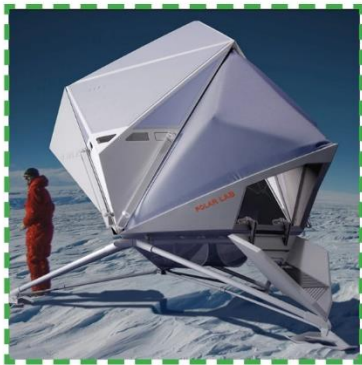


FACADE

LAW

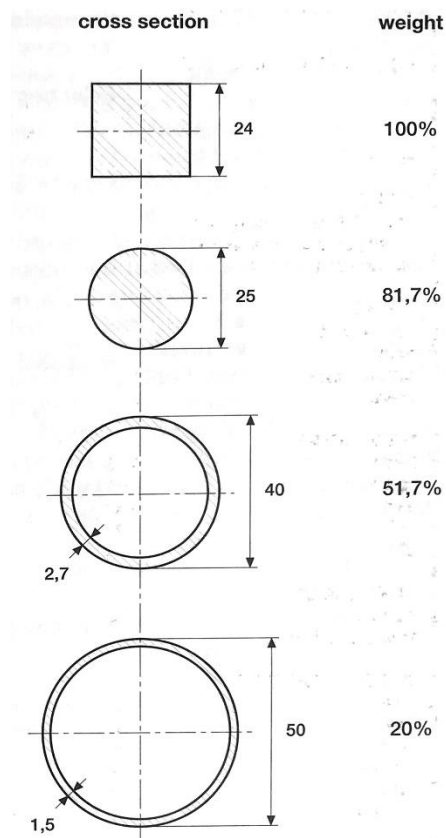
EXTENSION

INTEGRATION



| | -LASER | -WATER | -PLASMA | MILLING | NIBBLING | PUNCHING | 3-D PRINTING | HOT-WIRE |
|---------------------------|-----------------------|--|------------------------------------|--|---------------------------------------|---------------------------------------|--|--|
| MATERIALS | Almost all materials | Rubber Plastic Textiles Paper | Conduc- tive & raw materials | Wood Foam Cardboard (aluminium) | Steel Brass Aluminium Copper | Steel Brass Aluminium Copper | 'Structural ink' Concrete Mud | Expanded materials: polystyrene Styrodur |
| MATERIAL THICKNESS | 400 mm | Up to 350 mm | 3000 mm | Up to approx. 250 mm (with 100 mm drill) | Up to 8 mm | Up to 8 mm | Variable to materials and machinery | Unlimited, only limited by size of the wire |
| SIZE SEAM | 0.1 - 0.5 mm | 0.1 - 0.25 mm | 0.8 - 1.5 mm | 1 mm dependent on the milling head | 0 to 5 mm | 0 to 3 mm | Not applicable | Depending on thickness wire and height electricity |
| SPEED | 300 m/min | 35 m/min | 6 m/min | Approx. 10 m/min | 1200-2800 strokes/min | 1400 strokes/min | Variable to both machinery and materials | Variable to both machinery and materials |
| FINISHING NEEDED? | Dependent on material | Dependent on material | Yes, grinding | Yes, grinding | Yes, grinding the edges | Yes, grinding the edges | Usually not | No |
| GEOMETRY OPTIONS | 2-D | 2-D | 2-D | 3-D | 2-D | 2-D | 3-D | 2-D & 3-D |
| ENERGY CONSUMPTION | 100 kW | 37 kW dependent on pump | Approx. 80 A | 18 kW | 25-50 kW | 25-50 kW | Variable to both machinery and materials | Variable to both machinery and materials |

Digital fabrication techniques (Remmerswaal, 2015:33)



Weight reduction in structure (Beukers, 2005:169)

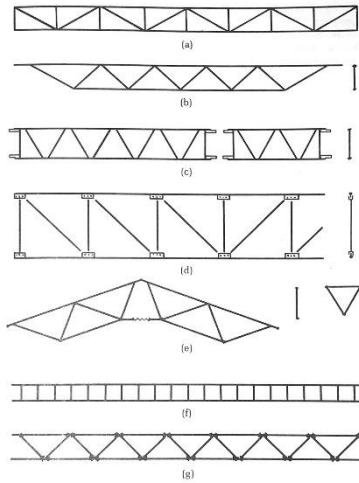


Figure 9.1 Types of prefabricated beam.

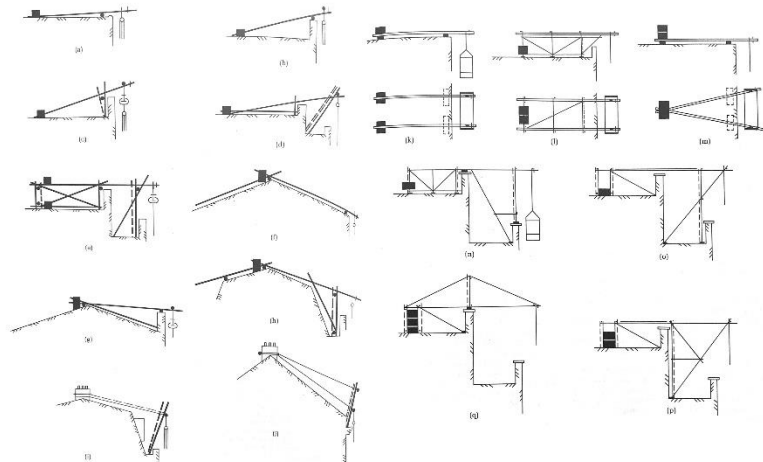
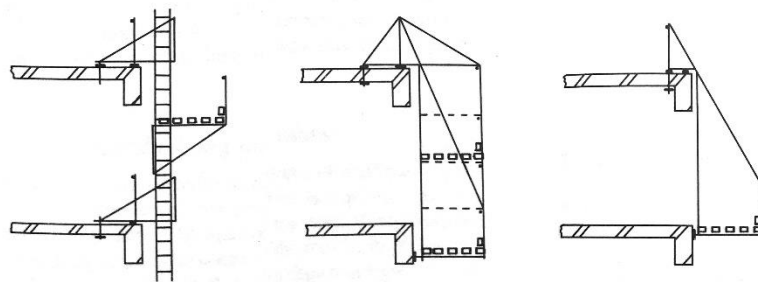
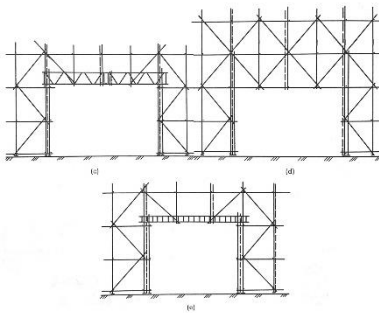


Figure 18.1 Staged scaffold roof top.



Various scaffolding types (Champion, 1996)

Table 2.7. From BS 5973 1990 Loads on normal access and working scaffolds of tubes and couplers

| Duty | Use of platform | Distributed load on platforms | Max. number of platforms | Commonly used widths using 225 mm boards | Max. bay length |
|---|--|---|---|--|---|
| Inspection and very light duty | Inspection, painting, stone cleaning, light cleaning and access | 0.75 kN/m ² 75 kg/m ² 15 lb/ft ² | 1 working platform | 3 boards | 2.7 m |
| Light duty | Plastering, painting, stone cleaning, glazing and pointing | 1.50 kN/m ² 150 kg/m ² 30 lb/ft ² | 2 working platforms | 4 boards | 2.4 m |
| General purpose | General building work, including brickwork, window and mullion fixing, rendering, plastering | 2.00 kN/m ² 200 kg/m ² 40 lb/ft ² | 2 working platforms + 1 at very light duty | 5 boards or 4 boards + 1 inside | 2.1 m |
| Heavy duty | Blockwork, brickwork, heavy cladding | 2.50 kN/m ² 250 kg/m ² 50 lb/ft ² | 2 working platforms + 1 at very light duty | 5 boards or 5 boards + 1 inside or 4 boards + 1 inside | 2.0 m |
| Masonry or special duty | Masonry work, concrete blockwork, very heavy cladding | 3.00 kN/m ² 300 kg/m ² 60 lb/ft ² | 1 working platform + 1 at very light duty | 6 to 8 boards | 1.8 m |
| Masonry or blockwork with storage capacity | Masonry and blockwork where large amounts of materials have to be stored on the platform | 4.50 kN/m ² 450 kg/m ² 90 lb/ft ² | 1 working platform + 1 at very light duty | 8–10 boards | 1.6 m |
| Special duties defined between the user and the scaffolder | | 6.00 kN/m ² 600 kg/m ² 120 lb/ft ² | By special arrangement and design accounting also for point loads | | To be calculated |
| Heavy construction units, shuttering units or equipment, plant, hoists, etc. Impact forces must be taken into consideration. Loads must be clearly stated to the designer | | | 1 special working platform + 1 at very light duty | By special arrangement | To be calculated. Consider double standards |