ROOF STACKING:
Learned Lessons from Architects

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Preface

This report is a part of a PhD research project entitled “Dencity: Zero Energy Lightweight Construction for Urban Densification” carried out at Liège University in Belgium. The project promotes for extending vertically the rooftops of the existing buildings as a sustainable approach for urban densification in the European cities. The project further develops a system that aids the decision making of roof stacking on multiple levels; urban, structural and environmental.

The presented information is based foremost on interviews with knowledgeable architects from different European countries who have experience with roof stacking projects. This report addresses architects, engineers and researchers who work on and have interest in roof stacking projects as way to densify cities. We aim to provide the reader with generic yet comprehensive information and contemporary construction methods used in roof stacking.
Acknowledgment

We would like to thank each of the architects by name: Gerardo Wadel from the La Casa por el Tejado (LCT) office in Barcelona, Spain; Georg W. Reinberg from Architekturbüro Reinberg in Vienna, Austria; and Antoine Galand from Atelier d'Architecture Galand in Brussels, Belgium, for giving the time and space to carry out the interviews and providing information and reflections from their experiences.

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1 Introduction

In a world that faces high rate of urbanization and immigrating populations towards cities seeking better opportunities or higher living standards, new urban agendas have emerged tackling problems related to increasing population and rapid urbanization (United Nations, 2017). As a mean to limit urban sprawl and increase urban densities, several researches explore numerous methods for urban densification with a main focus on optimizing the usage of the existing infrastructure in the cities, reducing carbon emissions and energy consumption (Dieleman & Wegener, 2004; Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; Marique & Reiter, 2014; Nabielek, 2011; National Research Council, 2009; Riera Pérez & Rey, 2013; Skovbro, 2001; Steemers, 2003).
On the building scale, seven methods of urban densification were observed. The first method is implemented on an individual level, by filling up the backyard of existing houses (Marique & Reiter, 2014). The second method takes place by filling up vacant land plots between existing buildings. Those parcels could be totally vacant or occupied by ground floor shops (Attenberger, 2014; Stadt Köln, 2011). The third method follows more intensive way by demolishing existing buildings and reconstructing higher ones (Attia, 2015; Burton, Jenks, & Williams, 2013). Fourth and fifth methods are based on the same concept of reusing existing buildings however more densely. The earlier method is applied by dividing existing multi-family houses into apartments or separate rentable rooms to accommodate more inhabitants, while the later concerns changing the usage of existing structures (not particularly houses), such as old factories and office buildings, into residential buildings. The last methods, sixth and seventh, focus on the usage of existing residential buildings rooftops. It is either limited to transforming old attics used as storages into inhabitable ones (Floerke, Weiß, Stein, & Wagner, 2014; Tichelmann & Groß, 2016), or by building additional stories over the rooftop (Amer & Attia, 2017; Attia, 2015), which is called Roof Stacking.
Roof stacking, which is defined as the added structure over the rooftop of an existing building to create one or more stories of living spaces (Amer & Attia, 2017), has multiple advantages as an approach towards urban densification. Roof stacking has the benefit of keeping urban morphological and architectural identity by conserving existing buildings and urban landscape (Nilsson, Nielsen, Aalbers, & Bell, 2014), not to mention the opportunity of using possible financial benefits into retrofitting existing old building. On the individual scale, several roof stacking projects took place as a way to increase livable residential spaces in cities that suffer from scarce empty land plots. On the national or regional scale, it has a potential to provide accommodation for increasing population in the major cities. Roof stacking is seen as an approach towards urban densification as well as financial revenue for house owners, and an opportunity to find room for inhabitants. Moreover, roof stacking has become an important topic that is being addressed with an aim to provide solutions and feasible means for implementation and replication.

This report aims to present a guideline for roof stacking construction methods that has been used by architects from different European countries who have experience in roof stacking projects. Three main objectives were set for this report; first, identifying the obstacles and challenges accompanying roof stacking projects. Second, presenting practical construction solutions and methods used to solve the problems associated with roof stacking projects. Third, validate and construct a classification for construction methods that are used for this type of projects. Case studies of Roof Stacking projects have been investigated in depth through interviewing architects who were responsible of the design and construction team in charge of project implementation. Based on semi-structured interview, a questionnaire consists of 7 main questions [see the Annexe] was designed and the interview was carried out with the architects. Extra questions and answers are included and reorganized to fit in to the questionnaire design.
The interviews were conducted face to face with three architects. The first interview was conducted with Gerardo Wadel, the director of the Research and Development department at “La Casa por el Tejado” or LCT office in Barcelona, Spain. The second interview was conducted with Georg Wolfgang Reinberg, the owner and director of “Architekturbüro Reinberg” in Vienna, Austria. The third and last interview was conducted with Antoine Galand, founding partner of “Atelier d’Architecture Galand” in Brussels, Belgium. Each interview lasted around one hour, recorded and filled up into this report [see the Annex]. Each architect has different approach in applying roof stacking, in addition to the fact that methods and approaches differed from one case study to another based on the context and limitations given in every project. However, it was hard to create a unified method for roof stacking construction, we were able to find a common thread that links all case studies and approaches together, while recommendations and solutions are proposed for every possible challenge on the design and constructional phase in addition to a single framework can unify the concepts engaged when applying roof stacking.

The methodology in this report follows a qualitative approach by investigating case studies with an application of thematic analysis. Further it aims to present a holistic portrayal setting with a pragmatic focus on actual construction techniques and onsite challenges and opportunities. In depth analysis is carried out through the case studies from the architects’ experience and is structurally presented. The results presents 5 categories of challenges that are common when applying roof stacking; Constructional; Building’s Services; Administrative and Social challenges; Financial; and choosing building materials. Further solutions and recommendations from real life experiences are proposed and recommended for each problem. The results are followed by common feature in prioritization different criteria when building on the rooftops. The facets of prioritization were defined as Financial, Structural, Certification, LCA, and Quality aspects. The ordering of those aspects differed according to the different context of each project.
Throughout the conducted investigation, it was found that it is difficult to create a unified system to apply roof stacking broadly. The urban, structural and administrative context creates uniqueness for every case. Yet, an outline could be drawn that gather the common the challenges and methods for all projects together and give the needed recommendations according to every case.

It is important to mention that the report focuses mainly on the technical aspects of roof stacking including structural, climatic and practical aspects. The considerations related to urban regulations, infrastructure, mobility, and the boarded vision of social acceptability are slightly investigated. This report does not aim to promote for through roof stacking as the ultimate solution for accommodating increasing population, yet it provides an overview for professionals working in the building industry, including architects and civil engineers, with common challenges of roof stacking in the cities and means to overcome it providing learned lessons from experienced architects.

The report is divided into five main sections. The first section includes an introduction to roof stacking and its importance. The second section presents the most common challenges of roof stacking from practical perspectives and the ways of solving such problems. The third section scale focuses on presenting different methods of construction and load bearing of new extension on the rooftops of the existing buildings. The fourth section gives and over view on the pros and cons of roof stacking from the point of view of the architects in addition to other literature who studies the same topic and handled it from its broader scale focuses on presenting different methods of construction and load bearing of new extension on the rooftops of the existing buildings. The fifth and last section concludes the learned lessons from the architects. The report is annexed with a copy of the questionnaire and the extensive interviews results that has been carried out with each of the architects.
Building on the rooftops is entirely different from building on the ground. Thus, several considerations have to be taken when deciding to build on the rooftops of existing building. We have listed possible challenges that faces roof stacking project and categorized them into 5 types as following:

- Constructional & building challenges
- Challenges related to existing building services
- Administrative and social challenges
- Financial challenges
- Challenges related to the choice of building materials

In the following section we discuss each challenge more briefly. We additionally provide possible solutions as a mean to overcome each challenge from the practical point of view of the interviewed architects in addition to previously reviewed literature.
Figure 1: Sleep well in the sky hostel Project, Brussels, Belgium
© Atelier d'Architecture Galand
The actual strength of the existing building

The first question that should be asked is whether the existing building is capable of holding additional structure or not. It is possible to determine the strength of the existing building either by theoretical calculations or through deep investigations. Theoretical calculation requires possessing the technical data of the building, starting from the specifications of the used buildings materials to the type of foundation and soil.

The second method is applied by investigating the existing structure through multiple methods used by specialized civil engineers. Among those methods there are visual inspection using thermal cameras and Geo-radar tools. Other methods are described under destructive investigation methods that requires to take samples and part from the existing structure to test it and determine its actual strength.

This type of investigation is necessary for aged buildings, because the structure of the old buildings has the tendency of changing its behaviour throughout the years. For instance, some walls that were not designed initially as shear walls could end up bearing weight due to the natural movements that take place in the soil and within the entire building. Through deep investigation, those types of alteration could be detected and further internal reinforcements could be applied when needed.

Foundation strength and soil allowable bearing capacity

The second challenge lies in the type of the foundation and whether it is sufficient to hold new structure. With the same methods used to identify the theoretical and actual strength of the existing building, the same is done for the foundations. It is important to mention that the capacity of the soil and foundation to bear additional weight changes due to earth movements and the consequences of soil compression throughout the years. In real cases, the soil surrounding the foundation is dig up to be inspected together with the foundations, and extra reinforcement is added to the existing foundations when needed.
Earthquakes and centre of gravity

When it comes to earth quakes, the existing building’s centre of gravity goes higher consequently as the building goes higher as sown in Figure 1. However, this is not the only consideration that has to be taken for earthquakes. Old buildings’ structures, especially those that were built before the World Wars, had no considerations for earthquakes and thus they are considered to be vulnerable by their own, which creates an additional challenge that has to be considered prior to deciding to add more stories. Maintaining the existing building could follow several methods, yet according to the feedback given by the interviewed architects for this report, one solution could be given as an example.

Figure 2: Centre of Gravity (CG) goes higher as buildings gets higher
In order to reinforce the existing building against earth quakes, either a ring concrete beam or platform is constructed that ties all the shear walls together on the rooftop as shown in Figure 2. The ring beam consists of steel reinforced concrete that supports the masonry walls by providing additional tensile strength. Thus, by adding the ring beam, the whole building gains more strength against earthquakes.

Ring beam acts as a roof anchoring to the new extension to be added on the rooftop. A complete platform can be added to the ring beams as a floor / ceiling slab, or a grid of steel beams that acts as a load transforming system (more details will be given in the next section).

Figure 3: Ring beam / RC Platform connecting all bearing walls of the existing building


**Structural calculation of the extension**

In some cases, structural calculations of the new extension may differ from conventional calculations. This difference may occur for several reasons; the most popular reason is due to the tendency of lifting the new extension by cranes to be fixed on the rooftop. This lifting changes the behaviour of the building elements, such as the columns, beams, frames, etc. from tension to compression forces and the vice versa, especially when locating whole or partial housing units rather than 1D or 2D elements. Thus, calculations has to take in consideration both, loads behaviour under normal circumstances and lifting process.

**Transportation, Lifting and installation**

As witnessed, the majority of roof stacking projects take place in already occupied cities. Thus, the speed in transportation, lifting and installation of the additional floors resembles a priority during the implementation. In terms of transportation and lifting, street widths and detailed logistics has to be considered even before the design process, as it will correspond to the allowable maximum dimensions of buildings’ elements and units. The type of cranes needed for transportation and lifting with differ as well. Installation of the added extension could be done in multiple ways according to the available opportunities. Yet, it represents an important challenge that has to be solved.
Figure 4: Housing project by LCT in Girona, Spain.
Source:https://media.licdn.com/mpr/mpr/shrknpl_800_800/p/1/005/0a2/3df/2763438.jpg
[2] Building services

HVAC

When it comes to Heating, Ventilation and Air Conditioning, it is important to consider integrating the whole system in both the new extension and the old building. Usually, the HVAC system of the existing building does not function efficiently due to one or more reasons, especially with old buildings. Moreover, by adding more stories, it makes it nearly impossible for the existing HVAC system to cover the new required capacity of the whole building. Thus, either a total renovation or an addition to the system has to take place. The method of addition or renovation would differ from one case to another depends on the capacity of the existing system and the detailed calculations.

Water, plumbing & electricity

Within the surveyed cases, there is a minor challenge associated with integrating or adding extensions to water, plumbing and electricity. However, it has to be taken in consideration within the design phase and apply modifications or additions when needed.

Figure 5: Residential building project in Kierling, Austria © Architekturbüro Reinberg

Urban regulations (heights & city administration acceptance)

The additional stories should comply with the existing local regulations. The most common regulations are related with the allowable maximum height, which is usually linked with the maximum height of the neighbouring buildings. Thus, even if the building’s strength can bear additional load, it has to comply with the urban regulations to get the approval and licence to proceed with the extension. Other regulations may entail the approval of the architectural design from the community and specialists working in the city administration as a mean to conserve the city’s identity and general look.

Social acceptability

When raising the topic of urban densification, social acceptability represents one of the main arguments that comes up. Social acceptability ranges from the acceptance of buildings ‘owners, to the neighbourhood and city level. The argument involves different perspectives and parameters starting from urban environment and questioning the need and limits of urban densification, to social justice and achieving fair distribution of neighbourhood densities that maintain a sustainable living environment in terms of open spaces, adequate population, transportation and human scale neighbourhoods.

Neighbours

Dealing with neighbours either from the same building or from the surrounding buildings can represent a real obstacle and barrier from applying roof stacking. Since the construction process is associated with noise, inconvenience or discomfort from the neighbours, an approval from the community associations and neighbours has to be granted prior to the construction process and they have to be involved within the design phase.
[4] Finance

The financial resource and revenue are very determinative to the success of the project. The financial resource depends on the project’s owner or interested entity, in addition to the amount of investment in relation with the requirements needed to apply roof stacking. If the case study requires excessive renovation or structural reinforcement that increases the risk of achieving financial revenue on the long run, it is very likely to be decided on halting the project, unless a financial revenue is not an aim.

[5] Building materials

The decision on the usage of building materials depends on several criteria. The prioritization of those criteria depends from either one case to another, or from the perspective of one architect and another. However, 5 aspects were found as the main criteria of choosing building materials for roof stacking:

Weight and Mechanical property

The total additional weight resembles the main concern when adding an extension to a roof, which is determined by the dead load of the new floor and the combination loads in general. However, the essential factor is represented by the weight of the building materials used, and as a general rule the lighter the better, yet other factors should be taken in consideration as shown in this section. Depends on the type of the material and the size of its section, the total weight can be determined. The most common materials used for roof stacking are timber and steel as main structural elements.

Timber sections works for both 1D and 2D elements, however steel sections can only be used as 2D elements as beams, columns and frames. Even though the density of steel is much higher than wood, in some cases using steel sections could be lighter than timber sections especially when using lightweight steel sections to cover large spans, which will require much thicker sections from timber to cover the same span. This returns back to the mechanical properties of each building material. From another side,
when comparing glass with timber when used as 2D wall elements, glass can weigh more than timber for example if triple glazing panels are used. Thus, a holistic calculation should take place simultaneously with the early and late design phases.

**Fire resistance**

When it comes to roof stacking, lightweight materials represents a good choice, since one of the main aims is to reduce the added weight on the existing building as much as possible. However, lightweight materials could be more vulnerable to fire than other materials such as concrete for example. Thus, materials have to be protected against fire to follow the requirements of fire safety. For example, when comparing timber with steel in fire resistance, each material behaves differently to fire. Timber is categorized as flammable material, which means in case of fire, it has the tendency to increasing the rate of fire to a certain extent. On the other hand, steel is inflammable. From another side of comparison, steel loosed its mechanical properties with fire, on the other hand timber does not lose its mechanical properties, however the cross section is reduced as the result of fire that turns to charcoal. Steel sections needs to be protected, for roof stacking and other projects.

**Acoustics**

Lightweight materials such as timber behave poorly to one or both types of acoustics depending on the type of timber that it used (solid wood, laminated, plywood, etc.). Acoustics impedance can be problematic. Thus, it is important to fulfil acoustic regulations by adding, for example, additional layers of insulation and integrate it in the constructional details. When considering another building material such as concrete, it has better acoustic impedance; however it is associated with much heavier weight. Thus, choice of building materials is required during the early stages of roof stacking design considering multi-objective approach.
Thermal performance (Insulation and thermal mass)

The thermal property of the building envelope is essential in maintaining indoor thermal comfort especially on the rooftop. By adopting the assumption of using lightweight materials when building up the roof extension, as a consequence, the architects tends to use lightweight materials for construction. Lightweight materials do not have high thermal mass in terms of thermal characteristics, which means that they have no tendency to store heat and regulate indoor air temperatures. Therefore, it is important to integrate high insulation in the building envelope and secure air tightness without going through the risk of overheating during the summer seasons.

A good combination of wall sections in addition to an efficient active system should be provided in order to maintain indoor thermal comfort. Building envelope design will differ from one region to another according to the local climate. Thus, As a mean to secure indoor thermal comfort, environmental calculations should be taken inconsideration in the early design phases of the project. In addition, the architectural design should employ environmental strategies in order to regulate indoor temperatures.

Ecological purpose

The importance of the Life Cycle Assessment (LCA) of the used building materials will differ from one project to another. Usually, the importance of using this criterion is raised when the project aims to gain an ecological certification from a local authority or an international one. According to the investigated case study, however LCA usually does not have a priority within the criteria of choosing building materials, it is important to mention.
[6] PRIORITIZATION OF ROOF STACKING OBJECTIVES

Each of the architects were given a hexagon with six criteria to be prioritized from their point of view or from the requirements of the projects that they have worked on. Some architects proposed different results according to whether different projects or different points of view between them and the project’s owner. The hexagon equivalent to six criteria was then reduced to a pentagon with five criteria for better relevance. Below in Figure 6, the accumulation of the five results is presented in one picture.

![Figure 6: Accumulative results of roof stacking prioritization](image-url)
Even though the results had a lot of differences, two main criteria were dominant; structural loads and comfort. Those two aspects were found to have the same importance in all majority of the projects. However, in some cases the loads didn’t seem to have that importance due to the strength of the existing structures that represented no big challenge for the architect to deal with. Yet, achieving comfort was set a priority for all of them.

Certification system and finance come in the second stage with their tendency to fluctuate according to the nature of every project and its requirements. It was found that certification systems weren’t a target in itself as much as it is usually required by property owners as a mean to secure a specific quality as well as promoting for their buildings in one way or another. Whereas the finance was fluctuating for two reasons; the first is the difference between the interests of the different stakeholders involved in the project. Second, it counted on the source of budget available for each project. LCA comes at the last stage, which does not seem to gain that much importance unless it is associated with certification system of other purpose.
3 Roof Stacking Construction Methods

A classification for the possible construction techniques has been carried out earlier by the same author through investigating over 60 case studies for roof stacking projects around Europe (Amer & Attia, 2017). Accordingly, it was taken as a primary reference for the architects to reflect on it, and to identify the techniques that they have been using in their projects.

Construction methods were divided into two parts:

- Load bearing methods
- Installation methods

Applied load bearing were found to follow one of two methods; load bearing on existing structure, and load bearing with additional reinforcement. Load bearing on existing structure was found to follow one of two paths; either by bearing loads directly on the existing shear walls or indirectly through a load transferring system or platform. While installation of new extension follows as well on of two methods; either installation of full modules manufactured offsite, or assembling building elements onsite.

It is important to mention that there were two versions of that classification. The first version was given to the interviewees for reflection and validation. Accordingly, a second version has been formulated according to their feedback on how things are preceded in real life. In the outcome section of this report, the reflections will be directed to the newer version of the classification for better understanding.
[1] Load bearing methods

Load bearing methods aim to explain the used approaches of bearing additional loads on the existing buildings for roof stacking as witnessed in real life. Thus, we are going to present the contemporary used methods rather than illustrating new approaches or techniques. Two main approaches were found for roof stacking. The decision making on the followed approach is based on the actual strength of the existing building and structural configuration. The main two approaches are load bearing on existing structure either directly or indirectly, and load bearing with an additional reinforcement.

In one project, multiple methods and approaches could be used based on the actual strength and required architectural design. More detailed information about real case study could be found in the Annex in one case study that has been investigated made by Atelier d’Architecture Galand, where additional floor was added on two different buildings with two different structural configurations. Thus, two methods of bearing loads were used in one project with multiple considerations.
Load bearing on existing structure

Since most of the projects were built on existing buildings that dated from the 19th century, it was found that the majority of the roof stacking projects counted on the structure of the existing buildings to bear the loads coming from the new extension. Two approaches are found under this method. The first is by direct bearing of the existing structure with a total respect of the existing structural configuration. The second is by indirect bearing through load transformation system or platform.

(A) Direct load bearing

Direct load bearing respects the structure of the existing building. The added structure can be applied either parallel to the old structure or perpendicular. Perpendicularly added structure could be obtained only by adding 2D elements, such as timber wall panels, which act consequently as new bearing walls for the additional floor. In one project, both ways could be used according to the new extension’s required design.

Applying direct load on the existing structure requires a ring beam, for old masonry building, as transition elements between the new and old structures. For skeleton or concrete structures, direct bearing could be applied directly without ring beams.
(B) In-direct load bearing

On the other hand, the majority of the projects used load transferring system when applying loads on the existing bearing walls. Load transferring system is composed of ring beams made of reinforced concrete that bundles mainly the exterior walls together before adding a grid made of steel beams that is designed to receive the loads from the added extension.

Load transforming system can be substituted with a load transforming platform or level, which is well known as “Lastverteilungsgeschosse” in the German language. However a platform would add more weight on the existing building, it provides further design flexibility for the upcoming additional level. The different between each system is illustrated as shown in Figure 5 & 6 for better overview. On the other hand, direct load bearing on the shear walls can be applied by different methods as concluded.
This category is the most common method used with old buildings from the 19th and 20th century that uses bricks and shear walls as their main structure. The strength of the existing building plays an important role first in defining the capacity of that building to hold more weight or not, and second in defining the most appropriate load transferring method together with the prospect design of the new extension.

The picture was taken from *La Casa por el Tejado* office in Barcelona. LCT office represents a live case study for roof stacking project using this indirect load bearing techniques through loads transforming system.

*Figure 7: Live cross section from LCT office in Barcelona © Mohamed Amer*
Figure 8: Usage of 2D elements as bearing panels rested parallel & perpendicularly on bearing walls of the existing building
Figure 9: Load distributing through a platform made of reinforced concrete
Figure 10: load Redistributing system composed of RC ring beam and steel beams designed specifically according to the new structure
Figure 11: Usage of 1D elements in the new extension. An opportunity of making a recess from the buildings boarder for terrace design or to comply with urban regulations.
Load bearing with additional Reinforcement

Additional reinforcement was found to be applied on two different scales. The first scale on a minor level of reinforcing some elements of the existing buildings that have been deteriorated or altered its structural function throughout the years. Additional reinforcement can be represented in additional frame or supported beam for some walls or rooms. On the other hand, a major level of reinforcement includes the reinforcements of foundations, soil or adding columns and beams supported from the ground level to the new extension. These types of bearing methods are costly, however they are only applied when the local or the function of the existing building is irreplaceable.

Types of additional reinforcements

There are multiple techniques of reinforcement that are being used (Papageorgiou, 2016). Each technique is used according to the element that is required to be reinforced

1- Fibre reinforced polymers (FRP) for Columns, beams, slabs & walls
2- Concrete jacket with additional reinforcement for Columns, beams & walls
3- Steel jacket technique for Concrete Columns
4- Bonded Steel elements for Slabs
5- Externally bonded steel strips for Walls

Load bearing with additional reinforcement
[2] Installation methods

Based on the interview results, some modifications have been carried out for the illustration for the installation techniques to comply with the actual conditions that take place with real projects. The primary level of categorization remained the same; however, the changes took place on the secondary level. Yet, two main categories were remained the same as following:

Offsite assembly

Offsite assembly is similar to the offsite construction concept. Building elements are assembled offsite to form complete or partial 3D modules. Those modules are transferred to the site, lifted and installed on the rooftop of the existing building. Such a method of manufacturing and installation requires a full coordination and integration between the designer and the manufacturer, in addition to the option of having such manufacturing company that provides such a service.
Moreover, 3D modules or semi-modules assembly requires high quality off-site manufacturer. Exceptional cranes and specialists take the responsibility of transporting and lifting up the modules on the rooftop, while the rest of the crew takes the responsibility of locating the lifted modules precisely on the rooftop. According to the LCT office in Barcelona, streets’ widths of the Eixample district helps manufacturing modules to reach up to 22 meters long each. This method has a lot of advantages in terms of reducing the amount of time needed onsite for transporting materials, lifting and occupying the street and the building. It is relatively the fastest method among all the categorized methods. However, it needs special conditions and facilities that ranges from the urban context and availability of a manufacturer that provide such complete and transportable modules. One complete floor can be lifted up and assembled in a range of one up to three days depends on the size of the project. Additional time is needed before the transportation and installation process, where the rooftop of the existing building is prepared to receive the additional modules, and another time after installation to finalize the interior spaces, which could reach up to three months; however, it does not cause a big hassle to the occupants or the surrounding neighbours.
Figure 12: Offsite 3D modules manufacturing at Mothership, Barcelona
Source: http://mothership.center/wp/

Figure 13: Lifting 3D modules over the rooftop in Barcelona
Onsite Assembly

Assembly onsite can occur for either 2D or 1D elements depends on the method of construction that is followed by the architect and according to the multiple constrains that are faced within the design process and onsite, such as street width, available cranes, rooftop conditions and available facilities.

(A) 2D elements assembly

The first method of assembling 2D elements on the rooftop consumed more time relatively when compared to installing 3D modules. It counts on precisely fabricated walls and slabs in the factory with numbering, which are transported and lifted by smaller cranes and assembled on the rooftop directly. 2D elements may include doors and windows and may not, however they are usually having only the ready cuts while the other elements come at a later stage. The most important thing that has to be taken in consideration in this method is the design of the joints between the different elements. They have to be included and fabricated in the 2D elements before it arrives onsite.
Figure 14: 2D plywood assembly early phase, Kierling, Austria © Architekturbüro Reinberg

Figure 15: 2D plywood panels assembly late phase, Kierling, Austria © Architekturbüro Reinberg
(B) 1D elements assembly

The second category includes assembling 1D elements, such as beams, columns and frames, onsite and a total conventional construction such as by erecting walls and columns onsite, however the later method could be rarely considered. Onsite construction consumes a lot of time compared to onsite assembly, and this method is followed under special conditions. Such conditions should secure enough time, acceptance from the neighbours and having the space to assemble and connect the elements together onsite. In the project that has been done by Atelier d'Architecture Galand, they used the courtyard of the hostel to locate the 1D elements, assemble them together and lift it up to the rooftop as a fragmented building envelope. In that project, the existing roof was functioning during the construction process before they switched its function to the new one, which was one of the main reasons to choose this method in construction.
Figure 16: 1D timber elements assembly early phase, Brussels, Belgium © Atelier d'Architecture Galand

Figure 17: 1D timber elements assembly late phase, Brussels, Belgium © Atelier d'Architecture Galand
Summary

As mentioned in the outset of this section, an earlier classification has been carried out based on 60 investigated roof stacking projects around Europe. The earlier classification was presented to the architects and we got their feedback from a practical and in-depth point of view. Accordingly, modifications were carried out and presented in this report.

The aim of that review was to modify and validate a categorization of roof stacking construction methods within an analytical theme. This analysis provides criticism on each method as a mean of developing criteria that aids the decision making process of roof stacking.

It is important to note that this classification is carried out from structural design perspective. However, there are no mathematical models or calculation in this phase, the decision on the construction method is aimed to be taken in the early design phases. We are aware of the inevitability to conduct full structural analysis of the existing building and the new extension. Thus, we suppose that calculation phase are done in later phases of project design and should solely be done by specialists, while acknowledging the fact that every single project would require exclusive innovative approach to counter specific onsite problems. Yet, we claim that possible onsite problems and solutions would lie within the suggested methods on the abstract level.

Lastly, the investigation of roof stacking project focused on residential use building typologies categorised under low or mid-rise building, with additional stacking up to 3 more stories. Thus, high-rise buildings with multi-stories extensions are not included within the proposed classification and construction methods.
4 Roof Stacking Benefits & Drawbacks

Roof stacking was found to be useful for urban densification, accommodating increasing population and reducing carbon footprint in multiple cases. However it is not considered as the ultimate solution as it has its drawbacks and considerations. In this section, we analyse the benefits and drawbacks of roof stacking from 4 different perspectives as follows:

1. Urban Context
2. Finance and revenue
3. Constructional aspect
4. Environmental & Ecology

The analysis was first carried out and presented from the points of view of the interviewed architects, and further it has been supported by literature. The following tables illustrate the pros and cons of roof stacking within each perspectives.
[1] Urban context

Roof stacking in the urban context is meant to address principally the problem of increasing population in the major European cities, either naturally or by local and international migration of populations seeking better job opportunities and facilities in the cities. From this perspective, we try to present the clear benefits of promoting roof stacking for urban densification while highlighting the considerations that has to be taken care of before and during roof stacking.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>• Roof stacking was found to be very useful as a consequence scarcity of empty land plots in major cities.</td>
<td>• Over densified city can lead to several consequences in terms of mobility and population over congestion.</td>
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<tr>
<td>• It resembles an opportunity to accommodate increasing population either due to internal or external migration seeking better employment and financial opportunities in major European cities.</td>
<td>• When considering densification on the neighbourhood level rather than city level, it could inhibit a sense of injustice. Thus, a holistic strategy for the whole city without favouring one district on another.</td>
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<tr>
<td>• It preserves the identity of the city by keeping its old buildings and not demolishing it for the sake of constructing higher buildings.</td>
<td>• Roof stacking may not be able to increase urban densities within the required limits when compared to other methods such as demolishing and reconstructing higher buildings, which is due to several constrains that the process of stacking entails.</td>
</tr>
</tbody>
</table>
[2] Finance and revenue

The financial process and aims differ from one project to another. On one hand, it can be funded by private or public sector. On the other hand, a project may target a financial revenue on the long run, or just to suffice targeted aims such as building renovation, or just to afford building the new extension. In the following table we explain briefly the associated pros and cons of roof stacking project from the financial perspective and based on the experiences of the interviewed architects.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
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</thead>
<tbody>
<tr>
<td>• On the individual scale, it is considered to be a very good opportunity of investment for house owner either with the intention of selling or renting.</td>
<td>• Additional costs may be required to install elevators, if not existing in the original building, rather than additional reinforcement when needed for some parts of the building.</td>
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<tr>
<td>• It requires less financial capital to invest on the rooftop rather than buying empty land plot, when found, inside the city.</td>
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<tr>
<td>• It inhibits the opportunity to finance existing buildings to apply a total retrofitting renovation and thus reduce energy consumption and consequently CO2 emissions</td>
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</table>
Constructional aspects have been discussed in details in the previous sections of this report. Thus, this table briefly summarizes the previously mentioned points.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>• When having the good circumstances to apply roof stacking in the city, and when the construction process includes a stage of an offsite manufacturing and assembled directly on the roof, it entails a higher quality of manufacturing, since all the parameters are being under control in the factory. Second, it consumed much less time for onsite construction.</td>
<td>• When applying roof stacking over a building, it has the tendency to cause troubles or annoyance to inhabitants, since it is nearly to evacuate the building while construction. Thus, a rapid and efficient installation are highly required in such cases</td>
</tr>
<tr>
<td></td>
<td>• It requires further consideration when doing the structural design, since it differs from conventional construction process of building on land. Actual strength of the existing buildings, their foundation and soil bearing capacity are vital in the process of design and decision making.</td>
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</table>

In the following table, the topic of environment and ecology is analysed based on the conducted interviews. Thus, it is important to mention that it does not include reflections from other literatures that are previously done in this topic.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
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<tbody>
<tr>
<td>• It is considered to be a sustainable approach for urban densification compared to other methods</td>
<td>• It has the tendency to reduce the amount of outdoor daylighting when it is given the opportunity for multiple additional stories. Not to mention blocking the view on some neighbours when given the final approval from the society and the city administration.</td>
</tr>
<tr>
<td>• It contributes in the reduction of carbon footprint by limiting urban sprawl and conserving urban landscape</td>
<td>• It helps reducing the rate of Vehicles Miles Travelled (VMT) and external mobility when supported by a highly efficient transportation network inside the city</td>
</tr>
<tr>
<td>• It helps reducing the rate of Vehicles Miles Travelled (VMT) and external mobility when supported by a highly efficient transportation network inside the city</td>
<td>• On the broader scale, it maintain existing resources resembled in the existing buildings</td>
</tr>
</tbody>
</table>
Nowadays, several approaches are being proposed for urban densification from multiple perspectives such as regional development, urban planning, ecology, mobility, finance, social acceptability and architecture. In this report, we aimed to portray a holistic synopsis on roof stacking as an approach for sustainable and efficient urban densification. Several notions have been tackled in this report that occupies the platform of construction sector in Europe. Those notions include but not limited to offsite construction, Modularity, building renovation, lightweight and timber construction.

Roof stacking is a part of a building story. It has been witnessed and practiced since ages for several reasons. Nowadays, it has been an increasing phenomenon that acquires a sense of urgency rather than a luxury on the urban and regional level. However, we found no systematic approach that promotes for roof stacking on the urban, constructional and social level. Accordingly, and as a part of an ongoing research, we aim to realize a systematic framework for roof stacking that identify and classify roof stacking construction methods from different outlooks as a first step towards aiding an informative decision making process.
Throughout the interviews and the investigated case studies, it was a challenging task to create a unified method for roof stacking whether from a constructional or architectural perspective. Each project has different challenges that need to be tackled individually and simultaneously. Yet, it was possible to list and further categorize those methods.

The strengths of this report lies in the approach of conducting interviews with three architects from different European countries and approaches. The report investigates in depth and focuses on roof stacking projects not as an optimum solution, but only as a mean for urban densification while giving an objective analysis with further recommendations for an optimum application. However, the number of conducted interviews cannot be representative; it is counted as a qualitative approach of investigation. The methodological orientation of such method relies on thematic and content analysis rather than statistical one. It aims to present a holistic portrayal setting with a pragmatic focus. Yet, more investigation and interviews are recommended as a mean to strengthen the analysis results, in addition to giving more detailed constructional details and applications.
ANNEXES

INTERVIEWS (EXTENSIVE)
FIRST INTERVIEW

**Place:** La Casa por el Tejado (LCT) Office in Barcelona, Spain

**Date & Time:** Wednesday 1st of March 2017 @ 16:30

**Interviewee:** Gerardo Wadel, Director of Research & Development Department at LCT and Co-founder of Societat Orgànica

**MA:** Why do you find roof stacking a good solution for urban densification?

**GW:** In Spain, the urban spaces has been growing between the 19th century and the 21st. The ecological footprint has increased by 40% with all the occupied spaces in its entire life. Therefore, this created a type of a city seen just as a room to sleep in. The environmental and social perspective, such as having the access to cultural locations and services, have faded away. Earlier, there were some experiences with vertical extensions here in the city before “La Casa Por El Tejado” has started, which raised the question whether it is possible to find land on the rooftops and offer additional houses in the in the *Eixample* district in Barcelona. Earlier studies were made by LCT found more than 2,800 buildings with the potential to build on their rooftops (Moran, 2015), and 4,000 in whole Spain (this is only according to LCT primary investigations). Another study that was made by APUR showed that 12% of the parcels in Paris has the potential to be vertically raised (Alba et al., 2014).

**MA:** According to the given illustrations, which method do you usually use in your projects?

**GW:** Those illustrations are very interesting and allow you to understand quickly the different ways to do this process, we can identify exactly what is our way! Our method of construction and load bearing aligns with A1 technique. More specifically similar to A1.2, which resembles bearing the loads though a load transforming system (a frame of load distributing system) that is composed of concrete beam along the exterior walls of the old buildings with crossing steel beams. Figure 4 is taken from LCT office in Barcelona,
which shows a live cross section for the load transforming system through ring concrete beam in grey and the white steel frames that connects the old building with the new one. However, we never used the A1.1 method because we do not use 2D linear elements in the construction such as beams and columns that has the tendency to connect from wall to wall. Instead, we build full modules that are built on one century old building that needs an interface where the new loads can be freely distributed.

Generally, the illustration represents a wide part of possible techniques that can be used. In our case, if we are working in another context different from that in Eixample in Barcelona, it would have been very different. We can assure now based on our experience of 10 projects, there is one case where we have to reinforce the existing structure. That case had an open ground floor due to the commercial use, where there are four or six columns made of old steel and the receiving the building loads which arrives from the beams and concentrated on the columns to the soil. And it was a very strange and unusual case for the transition of the loads, we consider this columns are not capable to receive an overload. By practice, we never did additional reinforcement to any of our projects before. However, there was only one case under investigation in Buenos Aires, where it had two stories and wanted to be extended up to six stories. In that case our studies showed that a new independent foundation has to be made to make it possible.

According to the installation techniques graph, we use the onsite assembly of prefabricated units (B1.1), where the modules arrives onsite 80% finished. But applying the installations, windows, façade finishing and the upper part of the roof renewable energy appliances were constructed using the hybrid method (B2.1). On the other hand, the method of assembling prefabricated elements (B1.2) arrives on site 40% finishes, and it requires a lot of time to be finished onsite. In our prefabricated units’ assembly method (B1.1), we use the crane within a very short time, because it cuts the circulation of the cars and transportation system, where the local government gives only permissions on Sundays in case of Barcelona. Therefore, time, weather, comfort
aspects and lighting are very important to be adjusted and secured when constructing onsite. Therefore preparing the modules in the factory resembles the perfect solution for that case. In addition to the fact that we are working in a part of the city that suits very much that method, we have wide streets to move a crane and transport a module that can reach up to 22 meters long.

MA: How could you secure the structural stability of the whole building?

GW: We made a brief explanation on how the data and the values of the walls and bearing capacity are extracted in several publications. (Artes, Volpi, Wadel, & Marti, 2016; Artes, Wadel, & Marti, 2017). The foundation of the “Eixample” area is made of cross cutting integrated walls that are not independent. This type of building have walls separated with 3 or 4 meters that makes a grid in two directions and they work together. The walls are made of handmade bricks, while the foundations are 2 meters deep made of the same bricks in addition to stones or the rest of construction works. If the walls in the ground floor is 30 cm width, the foundation system is estimated to be from 45 or 60 cm width.

The first step is to calculate the strength of the masonry walls. To make this calculation you may need to cut a part of the wall and measure in the laboratory. Sometimes the lab measurements are bigger than the calculated ones. Therefore, we use the measurements that comes from the laboratory, in addition to the coefficient of security to comply with the construction standards. The second part is through investigating the foundation of the existing building and know their specifications in terms of dimensions, material type, state of conservation, etc. Third, we determine the tension of the soil under the foundation system. Those are categorized under the destructive analyses. For non-destructive analysis methods, we use some tools that helps us in the investigation such as the Geo-radar that determines the densities of the materials and approximately determine the strength of the structure. Another tool is the video cameras with a wire that inspect cavity walls or spaces that are not accessible without making destructive
analysis. Accordingly, we recalculate the actual strength of the existing building under investigation.

From a structural point of view we have to highlight one important point that is related to using the crane to lift the module on the top of the building. The structural forces are absolutely different when compared to the normal case. This is very important issue that has to be taken in consideration when making the structural design because a module that is developed to support vertical forces and loads is different from a module is designed to be pulled by a crane from 4, 6 or 8 points.

**MA: On which bases do you choose the building materials?**

**GW:** One of our main goals when creating that system is to make designs for light weight modules. The current modules weigh around 330 kg/m² and this is the third part of the current system that we have now made in situ with bricks, concrete and mortar. We are in the process of developing a new building system between 250 - 300 kg/m². It may seem to be a small difference, however it makes a big difference with multiple units. Some buildings have strict load bearing capacity, which require a very light weight building system to be possible to make this extension.

In LCT, we form the flooring slab by using a sheet of cold-formed steel with a layer of concrete. The steel is used for the tensile forces while the concrete is basically for acoustic and fire protection. It is very similar to the combination of steel and concrete in contemporary buildings. The slab can also be made out of timber mainly for three reasons; first, because it reduces the time needed to form the slab. Second, it is lighter. Third, it has lower embodied energy and CO2 emissions. However, using timber instead of concrete is accompanied by an additional cost of 50 euros per square meter.

Senda is a new tool that has been used in LCT and developed specifically for environmental aspects of the building sector and according to our experience with the local energy certification. In Spain, there is an obligation to make energy simulation to the building with a dynamic tool. Every project has to be compared with a reference
building, which is a building with the same boundary conditions complying with the minimum requirements. In order to achieve the certification, we have to make modifications on that project to reduce its energy demand.

There is the official one called HULC “Herramienta unificada LIDER-CALENER”, it can be roughly translated as the unified tool for energy demand limitation and qualification. In one hand, you have the energy demand and on the other hand you have the energy study of your project.

For example, in our research and development department, we have a focus on solving the possible problems associated with thermal bridges resulted from using steel frame for the module’s skeleton by using timber instead of steel for instance, in addition to the price, time of construction in factory, thermal quality, and infiltration that are highly taken in consideration.

**MA: How could you integrate the existing building services with the new extension?**

**GW:** According to our experience this is not a big problem. Regarding the electricity, in some cases you only need new extensions to and connections to the city grid. Regarding the sewage and piping, it is still useful to make only an extension without any additional system. However, in some cases, the old system has to be replaced or maintained to prevent future problems. The main challenge is usually concerning installing an elevator in a house because it is a very complex operation that may disturb the vertical circulation of the building, and there may be no place for a lift, so may need to cut part of the stairs or using the courtyard of the building. We had one case where it was impossible to install a lift because we didn’t arrive to an agreement with the local government related to dimensioning of the elevator, therefore we had to abandon the project. However, extending the stairs is not a big problem. To extend the stairs is not a big problem. In some cases we need to refine its geometry starting from the last existing floor, because the size between two stories could be different as you need to correspond to the height of the neighbouring buildings to combine the old with the new part of the
building, so this is a process with new approximations with old, new, neighbouring buildings, etc. Briefly, the main problem is with the dimensioning and geometry but not with the process of the system itself.

**MA:** What are the most common social or legislative obstacles that you face?

**GW:** However, making calculations, prefabrication in the factory, transport them on to the rooftop and applying finishing may sound complicated, it does not resemble a big problem or disadvantage. What stands against Roof Stacking is that it is a very long process especially when it comes to the obligation of making agreement with a lot of people. Due to the lack of experience from technicians, neighbours and citizen, the process faces more obstacles specifically with the lack of specific construction and urban standards for this special type of housing. In some cases, people think that this is an illegal process and it is associated with a lot of risks and with minor advantages. However, the addition of more stories is considered to be a part of the *story of architecture* and it is not something new. In addition, some buildings have a lot of problems that should be fixed prior to initiating an additional floor, which is considered as a part of the whole process. Sometimes it is too expensive that it wouldn’t be feasible even after a successful rental or selling of the new flats. There are many limitations that hinders roof stacking basically within the current urban standards in how to calculate the maximum height, volume or area that you are allowed to build within. For example, if a window is opened towards a neighbouring building, this resembles a restriction to that building to be raised by the fact of that there is a window opened on that side. After fulfilling the urban and regulative standards, the load bearing capacity of the existing building comes in the second phase. We kept in mind if that building is interesting to offer an amount of money to buy that right. Other things like legal aspects and urban standards, you can find up to 20 people with a right of property, so we need a lot of time and effort to make an agreement with all those people with different interests, ambitions, relationships and fears which are not sure for them, such as risk of collapse and security.
SECOND INTERVIEW

**Place:** Architecturbüro Reinberg Office in Vienna, Austria

**Date & Time:** Tuesday 7th of March 2017 @ 13:30

**Interviewee:** Georg W. Reinberg, Director of Architecturbüro Reinberg ZT GmbH

**MA:** Why do you find roof stacking a good solution for urban densification?

**GWR:** In the case study of Kierling, it was a form of densification. It was taken from an ecological point of view to use an existing building in a more intensive way. In that case we had to do a high level of retrofitting for the building. Since, the rents were limited and as a house owner he has no right to raise the rent on the inhabitants and therefore the budget was very limited. Thus, the densification of this project was taken from an economic point of view. It was a way to finance the project by renting or selling the additional apartments on the rooftop.

The land is very limited in the cities, and it is very expensive when it is found. Therefore, it is a good idea to building on the existing building stock. In Vienna particularly, the population is growing very fast. I find it applicable to other cities however every situation is different. However, it is more urgent to increase density in cities with growing population. In Vienna there is a lot of movement from small towns to bigger cities and also from other countries to the major cities.
MA: According to the given illustrations, which method do you usually use in your projects?

GWR: The illustrations aids in decision making as I believe that architects have to know the different possibilities for roof stacking because every house would have a different circumstances. Therefore, you have to make all your decisions and how to interfere based on every situation.

The illustration represents different techniques depending on the actual condition of the existing building. For example, in some cases you have restriction on the boarders of the construction as shown in Figure A, which is similar to method A1.2 however with no loads transformation through a platform but through metal beams instead. That method represents more Figure B as a load distributing system where you can locate your columns anywhere on it.

Figure A: Load distribution through metal beams

Figure B: Load distribution through concrete platform
Another way of bearing the loads from the new extension is through wooden panels. It works as shown in Figure C as you can load each panel on the existing building’s columns and it works as shear walls but in wood. In between the wood lattices, doors can be opened. We used wood panels in the case of Kierling in addition to steel beams at some parts.

As shown in the pictures, wall panels rests between two bearing walls. Some steel beams were added for better redistribution of the loads. However, the staircase had to be made completely in concrete for fire safety reasons.

In the case of kierling, load bearing panels were fabricated and assembles onsite. The cuts for the windows were made in advance in the factory, where the windows were installed in a later phase, which is more equivalent to B2.1 technique.
**MA: How could you secure the structural stability of the whole building?**

**GWR:** Every house is different. You will need seriously to investigate everything in each building to define how the structure functions in the building. We have specialized civil engineers that do the calculations needed for the building in order to determine its actual strength and capacity in holding more weight. Sometimes they need to open some parts of the building and investigate the type of construction. In addition, it is very important to investigate the foundations of the building and study the changes that happened to the building during its lifetime. In some cases, some of the walls of the old buildings that were not designed as load bearing turns to bear loads by the factor of time and possible movements. In other cases you may find torn down walls that need to be supported by steel frames. Therefore, before adding an extension all the elements of the existing building should be investigated in advance.

Therefore, first of all the whole building has to be investigated and to be figured out if it is possible to add more load based on its actual strength. For example, in Vienna, the houses are built with relatively strong external walls, which were made for fire structural stability reasons in addition to fire protection against the neighbouring houses. Second, all the bearing walls have to be connected with each other through a concrete beam or platform as shown in Figure D, so that the whole structure becomes stronger. This connection is regardless the new extension. It is made basically to strengthen the existing building against earthquakes. When it comes to the new extension, the loads are distributed between all the linked walls for better design condition as shown in Figure E.
Wind loads do not represent a major concern when it comes to roof stacking, however earthquakes is more critical. This is because old buildings construction did not include earthquakes calculation measures. If you make a building higher, then by default the point of gravity is shifted to a higher level as shown in Figure F, which has to be considered within new earthquake calculations.
MA: On which bases do you choose the building materials?

GWR: The available materials to choose from when doing an extension to a building is always more limited than that when you do a new one. Yet, the ecological criterion is very important in our approach, therefore we build a lot with wood on the first basis. A second base is according to the actual situation of the building, how much weight can be added, and what the given spans to cover are. In some situations, steel is more suitable in covering long spans while being relatively more lightweight than timber.

Higher fire safety measures could be achieved for wooden panels for example by adding gypsum boards on each side of the wall panel. However, concrete complies easier with fire safety measure, we still use wood for ecological reasons and because it is lightweight. On the other hand, lightweight can have problems when used for roof stacking. Wood for example as a lightweight material do not have enough thermal mass to compensate with the fluctuation of the weather during the day and night. It has a higher tendency to create overheating during the summer, and to be very cold during winter if not well insulated.
To overcome the thermal mass problem, a clay covering of 5 or 4 cm could be added. Since the insulation would not help the problem of overheating, a very good protection against the sun has to be provided. In some cases you may need to add air conditioning to comply with the strict building regulation in providing indoor thermal comfort; however it would be a shame to do it in a housing project. In Austria the temperature has increased by two degrees, which is relatively higher than other countries.

For the case study of Wollzeile, the actual building was in a very good condition in term of the used bricks and mortar. The better quality the higher strength is given to the building. As a matter of fact, buildings that were owned by the rich used a better mortar that that were owned by the poor. Thus, the quality of the building did count in many cases on either it was built in a rich or poor area.

Based on these conditions, we were able to use concrete in the extension for two reasons; first, it was meant to link between the different walls of the building. Second, the concrete was used within the active strategy of the building and to avoid overheating problems in the summer. Water pipes were installed in the concrete as shown in Figure G. It uses the water under the building (there used to be a river under this land plot, which has been covered) by taking cold water and running it indirectly (through heat exchange) through the pipes in the concrete during the summer to cool down the building. While in winter, the water is connected to a heat pump that warms the water before going through the columns. The whole active system using underground water was integrated in the whole building and in the office. A false ceiling was made in the offices where there is cold water loops to cool down the offices.
MA: How could you integrate the existing building services with the new extension?

GWR: Very often they are needed to be exchanges that being renovated. It give sense to renovate an old building before adding a new floor to it, otherwise it is like giving a terrible house a new attic. Sometimes it is difficult to integrate new services with old ones that makes it more challenging. In Kierling we had to change everything including the old HVAC system, however we faced some design restrictions related to the existing pipes that we have to link with.

Figure G: Active concrete columns using underground water
**MA:** What are the most common social or legislative obstacles that you face?

**GWR:** The social obstacle is the most common one when doing roof stacking because usually people live in the building that you are stacking or renovating. Such problem could be solved through social organizations. For example in Kierling, we spoke with every single family before we start. We needed to be granted an approval prior to design and construction. Every family was visited with a social worker and technicians from our office. We had to listen to them and documented everything.

On the other hand in the case of Wollziele, we didn’t face the same obstacle because the building was empty except with a shop in the ground floor, which was much easier to handle.

Another obstacle is related to regulatory restrictions, because the design should be approved from the buildings commission that is concerned with protecting the old environment of the city, which is not objective in many cases and it is based on subjective process by getting an approval from a certain jury that you have to take their signature and licence to build.
THIRD INTERVIEW

Place: Atelier d’Architecture Galand Office in Brussels, Belgium

Date & Time: Monday 20th of March 2017 @ 14:30

Interviewee: Antoine Galand, Director of Atelier d’Architecture Galand

MA: Why do you find roof stacking a good solution for urban densification?

AG: In my opinion, I wouldn’t go for urban densification as the first answer because the cities are already dense. And it would be more efficient to demolish old houses and build higher ones if it is meant to increase the density of the cities. Yet, from an ecological point of view, in Brussels there are a lot of projects that regenerates the rooftops of the existing buildings, either by making green roofs with productive crops or by building over the rooftops, however the latter option wouldn’t be simple especially for old buildings. On the other hand, there are many office buildings that are made in concrete, where it is simpler to build dwellings on their rooftops.

However, in some cases where it is needed to increase the density of the plot with being able to evacuate the buildings from its inhabitants, roof stacking is inevitable. For example, the project “Sleep well in the sky” there was no other option than building on the rooftop of the existing hostel. Another option that we had was to build in the courtyard, but it was more pleasant to keep the courtyard for public gatherings and for outdoor activities.

However, we cannot increase very much for two reasons; the first reason is because the basement was very bad and the neighbourhood was not very high, so we couldn’t go higher. In Brussels you have specific rules that says that you can go as high as your neighbour but not more than 3 meters than the other neighbour.
MA: According to the given illustrations, which method do you usually use in your projects?

AG: In the case of “Sleep well in the sky”, A1.2 method was used more or less. We used also a part of method A2, because in our case study we made an extension on two different buildings at the same time. The first building was built in the 80th, while the other was built in the beginning of the year 2000.

The newer building was made of concrete walls, strong façades and foundations, therefore we could build on it easily. On the other hand, the older building was in bad conditions with a tendency to move around 15cm from the other building, and it was made of RC skeleton and façade made out of bricks. We had to respect the rhythm of columns of the older building for the first raised floor, however in the second raised floor the structure was made completely in wood and we had more flexibility in the bearing load design.

Regarding method A3, I think it is very expensive to make additional reinforcements to the building, however, it would be very interesting because there is the ability to keep the building as is and use its extended vertical space. There was a challenge to access the building with the building materials. So, the courtyard behind was used for assembling the 2D elements coming from the factory and lift it on the roof. The courtyard wasn’t very big, therefore the fabricated elements were not very big, they were in the size of fragmented building envelope. Thus, it is more equivalent to the method illustrated under the B2.1.

The construction process that had to take place while the hostel was functioning. This process was complex in terms of managing the different stockholders in a perfect timing. There were different enterprises working on it. Thus, there were a project manager to connect everybody, we worked a lot with him. It was one person who was the director of the construction enterprise.
MA: How could you secure the structural stability of the whole building?

AG: The level of challenges we faced in this project differed according to each building of the two buildings we had onsite. The first part related to the newer building was quite easy to design and to structurally solve. That part included the rooms and the corridor. On the other hand, the second part was much harder and more complicated to make its architectural plans, which included mainly the patio. We had to install big steel beams that connect the RC columns of the older building, and accordingly the new loads are settled on that beam. However, to use steel in Belgium, it has to be protected against fire. Therefore all steel beams were covered and protected for a safe usage. In addition, within out designs, we had to guarantee that the new extension can move according to the natural movement of the existing building independently. The new extension was divided mainly into two parts in the architectural plans as shown in Figure H. The main connecting element between each part is few stairs, where each part would not be affected if it moves a few centimetres from the other part.

Figure H: Architectural Plan of the Youth Hostel
MA: On which bases do you choose the building materials?

AG: In the case of “Sleep well in the sky”, it was more or less and obligation to use wood even though the owners opposed this idea due to the associated acoustic and fire problems with wood construction. From our side a good argument was conducted from an ecological point of view for wood construction, in addition to the fact that it was the only solution as lightweight material to be used on the rooftop of both buildings together. Wood in general is very good for roof stacking project as it is light, clean and easy to transport and construct. Yet, the acoustics of wood construction was a major issue in that project, since it was made for youth hostel, which is usually accompanied with more noise than in the normal cases. Therefore, the wood construction has to encompass several layers of insulation. That was from the construction side, however from the architectural design side, we found that making duplex rooms a smart solution. Duplex rooms actually helped solving acoustic and fire problems. More precisely, the duplex rooms occupied the space over the old building. Over the new building, solid wood has been used. However, solid wood does not have an acoustic problem with vocal sounds, it has problem with acoustic coming from friction and knocking. Therefore, a secondary thin layer was added to the wooden panels. We made a classification for all the materials according to NIBE, we had to do that for the Ecobatisseurs. Each material used on site had to be justified from an ecological point of view.

MA: How could you integrate the existing building services with the new extension?

AG: In terms of staircase and elevators, it is impossible to change their places and you have to respect it in the design process of the hostel. However, regarding the heater of the existing building, it was three times smaller than what we needed from a capacity and an ecological point of view.

Thus, there was a decision to include a new heater, ventilation system and water heater beside the existing one. All the new system installed was for the existing building and the new extension at the same time. We could use the old pipes of the existing building,
however, it had to be integrated with the new HVAC system. The first step that we had to keep the old system as is, because there were users already who needed hot water and heating system. The old system consisted of two heaters, we stopped one of them in the good season in summer, and then we just added the new system and linked them together. There was only one room for all the HVAC system in the old building which was not sufficient to include the space for solar heater, heater and ventilation system. Therefore, a new space was created especially for the ventilation system for the whole building, which was a big challenge to include it in the whole building. It had to take huge spaces in the corridor to be able to let the ducts through the corridors, which has ended up with 2.5 meter height. It was unfortunately not the optimum height however there was no other option. In general there is a huge part of the building was dedicated for the technic. That was one of the main problem that we find in the building. The size of the technic is three times bigger than the one that existed which was for the heater, cogeneration and solar heater. Regarding the electricity, there was no problem at all.

**MA: What are the most common social or legislative obstacles that you face?**

**AG:** It is different from who is rating, is it the architect or the project owner. Generally talking, it is always difficult to deal with the neighbourhood. In this project we had to deal with it before getting with the work itself. We were all the time under stress. But because we were dealing with the ministry for the hostel directly it was easier to get things done, which is different from the ministry of urban.

In Belgium there is a social consultation that has to be involved in the decision making of the project, where the neighbours are there too and where the negotiations take place. As we worked with *Ecobatisseurs*, there were people who came and visit the work space frequently to follow up the progress, materials installations, etc. Therefore people were very interested by this type of construction at the end.
QUESTIONNAIRE

1- What is the construction techniques (load bearing and installation) that you have used according to the Figures 1 & 2? If not any, what method did you use to connect the roof extension to the existing building?

2- What are the main building materials that are used in the construction (in terms of (a) main structure elements and (b) building envelope)? & Why?

3- Was keeping your new extension light-weighted one of your aims? What strategies did you follow to achieve that aim? How could you secure the structural stability of the whole building?

4- Which of the following challenges do you usually face when making roof extensions? (You can add other points that you see more challenging) & how do you overcome those challenges?
   (a) allowable bearing capacity of the soil
   (b) strength of the existing structure & foundation
   (c) wind & seismic loads considerations

5- What are the main design performance that you considered during design and construction (e.g. in terms of achieving passive house standard, thermal comfort, reducing energy consumption, Life Cycle Assessment – LCA, etc.) and how could you achieve them?

6- What are the most common legislative obstacles that you face (e.g. urban policies, right to light, parking, fire regulations, etc.)? & how did you manage them?

7- How could you integrate the existing building services with the new extension (e.g. vertical circulation, water, sewage, electricity, etc.)?

8- In your opinion, when is it impossible to apply roof stacking (e.g. structural, legislative, financial reasons, etc.), Could you give some examples?


ABOUT THE AUTHORS

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Mohamed Amer is an architectural engineer, graduated from the Faculty of Fine Arts in Cairo and he got his master degree from Stuttgart University under the master program of Integrated Urbanism and Sustainable Design (IUSD). His research focused on optimizing daylighting and energy consumption in buildings using parametric simulations. Afterwards, he was granted a fellowship from Transsolar Energietechnik GmbH in Stuttgart with a focus on climate engineering designs and consultancy for various projects all over the world. His initiative project aimed to develop retrofitting measures for existing buildings in Cairo to increase comfort and reduce energy consumption. Currently, Amer works as a PhD researcher in the Sustainable Buildings Design Lab (SBD) at University of Liège. His research aims to create a prototype for zero energy roof stacked housing to increase urban densities in European cities using lightweight construction.

Shady ATTIA

Shady Attia is an architectural engineer and professor of sustainable architecture and building technology at Liege University in Belgium. He is a faculty member of the United States Green Building Council and his area of expertise is high performance buildings (net zero energy buildings) and regenerative design. In 2014, he established the Sustainable Buildings Design (SBD) Lab. The lab is focused on identifying and evaluating efficiency measures, performance-based building design and monitoring techniques as a decision support methodology for building professionals. Dr. Attia works also as an independent consultant in the area of building energy efficiency and sustainability. As registered architect, and LEED accredited professional he worked with several governments for building efficiency programs as well as building design and energy consulting companies.
ROOF STACKING: Learned Lessons from Architects

Roof Stacking represents an approach to accommodate increasing population in the major cities around Europe, new agendas for urban densification emerge in response of finding sustainable solutions to use existing urban infrastructure in the most efficient ways. Several methods for urban densification are being proposed and seen in real life. One of those methods is roof stacking, which is defined as the added structure over the rooftop of an existing building to create one or more stories of living spaces. This report represents the results of conducted investigation on roof stacking method as a sustainable approach for urban densification. The aim of this report is to present a guideline for roof stacking construction approaches and methods and present the learned lessons through interviewing notable architects from different European countries who applied roof stacking. This report identifies the challenges and opportunities when applying roof stacking in addition to proposing recommended solution for the different obstacles that are faced when adding extensions on the rooftops.