DenCity: Zero Energy Light Weight Construction Households for Urban Densification

Mohamed Amer[1], **Shady Attia**[2]

[1] Université de Liège, Départment ArGEnCo, SBD Lab, email: *mohamed.amer@student.ulg.ac.be*

[2] Université de Liège, Départment ArGEnCo, SBD Lab, email: *shady.attia@ulg.ac.be*

Accommodating more populations in the cities is becoming an increasingly complex task, especially with the mounting local and global migration and the raising demand on housing. Thus, the application of urban densification has recently been put forward as a promising alternative to urban sprawling. By increasing the density in the cities, it offers potential opportunities for reducing carbon emissions, erosion of green fields and enormous investments to establish new infrastructures. Yet, there are many constrains when it comes to urban densification and huge lack of knowledge especially when it comes for roof stacking approaches.

This paper is a part of an ongoing research in the field of sustainable urban densification through providing innovative solutions for zero energy light weight construction. The focus aim of this research is to identify the gaps in the construction solutions for roof stacking, to feed in the innovation pipeline of the European construction landscape in the coming years. This paper presents a comprehensive review of different case studies and efforts in the field of roof raising and its repetition potentials. Based on a structured review, 8 different cases from three different European countries were sorted, placing a variety of methods in comparison with each other. The main contribution of this review lies in the analyses of the existing information in this field and the classification of the different validated methods and approaches that has been used. Finally, despite the existing challenges, it was found that the concept of roof stacking can be widely spread and applied in different contexts. Future research is going to investigate possible solution and structured scientific approaches to widen its application.

KEY WORDS: *Roof Stacking, Urban Densification, DenCity, Lightweight construction, Zero Energy*

1. Introduction

World population is growing exponentially. According to the recent studies by the United Nations, by the year 2050 it is expected that the population will reach 9.425 billion, with 32 % increase equivalent to more than 2.37 more billions (United Nations, 2015).

Studies report that urban growth became more expansive, with an equivalent or sometimes higher frequency than the urban population growth rates (Marshall, 2007). Given that 54 percent of the population lives in urban areas rather than rural ones, and it will increase to 66% by 2050 (United Nations, 2014). Thus, new neighborhoods are needed to be built, which push the borders of the cities creating larger outskirts with lower densities that contributes to the loss of farmlands, increasing carbon emissions and affects negatively the local climate of the region (Seto 2011; Hutyra et al. 2011; Angel et al. 2010). The harmful side of urban sprawling is always associated with the loss of farmlands, which has an irreversible effect on the local climate and forms a danger to the biodiversity (Seto, 2011).

2. Need for Densification

Accordingly increasing population and mass migrations, whether searching for better job opportunities or seeking better facilities and lifestyle, is inevitable. Before heading to build new neighborhoods on the outskirts of the cities or remote settlements; it is wiser to invest in the existing ones, by accepting the increasing population and to increase their efficiency and sustainability measures.

It is proven that high density urban development can reduce the total energy consumption and carbon emissions (National Research Council, 2009). Baring in mind that increasing urban density alone does not secure lower Vehicles Miles Traveled (VMT) for instance. Thus, there should be a package of polices that integrate the increasing urban density with higher concentrations of employments, good transit network, parking areas and carbon taxing system (Brownstone, 2008).

3. Methodology

This is a part of an ongoing research that aims to increase urban density, expand cost-effective housing opportunities and provide leadership to accelerate the transformation towards a low carbon community by validating design prototypes for different zero energy, lightweight construction systems and composite components. This research resembles a first step towards that goal. Thus, it focuses particularly on reviewing different roof stacking case studies around the world in general and specifically in Europe. A systematic classification and analyses have been conducted to illustrate different techniques and methods that have been used previously for roof stacking with the purpose of increasing density. The significance of this research lies in the identification of the existing gaps in the construction solutions to feed in the innovation pipeline of the European construction landscape and in the coming years. This research reports the challenges and opportunities for further utilization of such techniques around Europe and the Globe.

A primary review for previous cases for roof stacking has been conducted. Though, not all the cases have been taken in consideration for analysis and classification. Criteria for the case studies selection have been settled at the beginning to fit into the research scope and capacity. The case studies have been analyzed based on two factors; first the method of construction and second the basic materials that have been used during the construction. Finally, challenges and opportunities were illustrated by the end of the research to discuss its applicability and its tendency to be repeated.

4. Case Study Selection

Cases from around the world have been spotted, ranging from cases in developing countries to megaprojects in developed ones (Gill and Bhide 2012; Kruse and Torstensson 2011; Papageorgiou, 2016). Those cases had different approaches, yet the aim is one, increase density to accommodate the need for housing and increasing population. However, not all the cases have been analyzed for two different reasons; the first is due to research time and efforts limits. Second, the aim is to select cases that should have similarities to the context by which the research focuses on. Thus, the criteria that were set are based on the following:

4.1. Geographical context

Since the research is based in Belgium and targets the European context as a start, the cases that have been selected were based in different countries in Europe. All the cases were approved by building regulations at each's country, which is different from other cases, e.g. in India, which had totally different urban context and regulations. In addition the techniques that have been used usually differ according to the different geographical contexts and available technology.

4.2. Functional and scale context

Extra stories on the roof can hosts different functions such as for office or commercial uses. However, the research focuses on the residential sector and hosting increasing populations. Accordingly, this research is focusing on stacking that ranges from one to three stories.

4.3. Available Information

Many of the cases that have been spotted have no sufficient information to build an analysis. Thus, many cases have been excluded.

5. RESULTS

Eight case studies have been analyzed in this research. The cases from Paris, Rotterdam and Stockholm were all part of an investigation made by (ROBUST) a European research project that have studied building technologies that are associated with the improvement and over roofing of existing buildings using steel-based technology. The other cases from Spain and Austria were designed and developed exclusively by architectural offices; “La Casa Por El Tejado” from Spain and “Architekturbüro Reinberg ZT GmbH” from Austria. Based on the different sources of information, there was a natural categorization in terms of the themes that have been used for stacking techniques. However, the architectural office from Spain has stated a specific theme in their work that has been followed in all of six projects built in Barcelona and Girona in Spain. In this research, only three cases from Spain were analyzed out of six existing cases, due to the similarity in the techniques that have been used, and the same with the cases from Austria; two cases were analyzed out of four spotted cases.

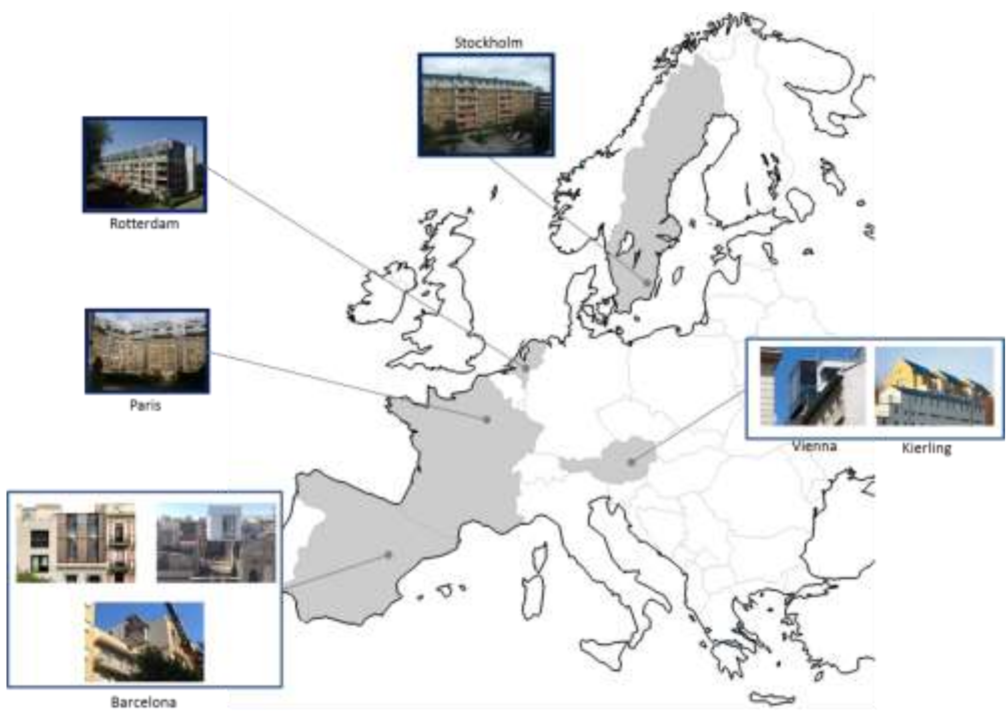

Figure 1. *Selected cases for analysis from different countries in Europe*

The architect from Spain states that their method of construction process takes third of a time than the conventional ones, which usually takes around 4 months. During the construction process, the existing properties of the building are rehabilitated, including the facades and common areas, installation or extension of lifts, replacement or relocating some community facilities, adjust the relation between stairs / flights of stairs with the installed lift, replacement of ornamental elements, and removal of precarious constructions and improve fire protection. Among other improvements the rehabilitation of the front facade, repair of structures of balconies, renovation of the interior courtyards, in some projects, the replacement of the original hydraulic mosaic floor are counted and recovery of the original coverings entrance hall. Thus, every case is unique in terms of the type of treatments that are needed, and the challenged that are being faced.

The Austrian architect had a general focus to the environmental and energy performance of the top up floors and the whole building. The addition of extra floors on the roof always had to meet passive house and energy efficiency standards. Moreover, and according to the feasibility studies, the budget always allows for a total retrofitting for the whole building, which resembles an important added value to the concept of roof stacking.

Table 1. *Detailed descriptions for the eight case studies and techniques that have been used*

No	Location	Description	Technique/s
1	Passeig de Sant Joan 59, Barcelona, Spain	Two penthouses with terraces have been added at the roof top. The total duration for manufacture and installation was three month. Rehabilitation of the stair well and elevator have been made afterwards	- The roof has been prepared with a structure to receive the added modules, - Modules have been manufactured totally in the factory and transported in whole pieces.
2	Còrsega 685, Barcelona, Spain	The original building is an old one, which has not been renovated for ling time. Additional three stories resembled a big challenge to be added to the old building; in addition, there were huge challenges to adapt the new stories to the original design.	- Extra weights have been removed from the roof (outlet box stair, roof cover, cornices, water tanks and storages) - The new construction has been calculated according to the existing structure capacity and removed loads - There was no need for any extra reinforcements, in return they have to use ultra-lightweight materials
3	Enric Granados 69, Barcelona, Spain	Two floors have been added, the fourth & fifth. This process took two months simultaneously with the manufacture of the panels. Total duration (including attaining the permit) is six month; two months roof preparation and panels manufacturing, and four months assembly and onsite task and finishing).	- The project was designed using 2D assembly light laminated wood frame system and semi-passive house insulation achieving an A level in energy efficiency rates & 60% less environmental impact. - Mineral panels (for fire resistance up to 2 hours), composite beams (wood & steel) have been used - The roof was prepared before the installation of the two stories (removal floor elements, making transition structure connections forecasting facilities).
4	WollZeile, Vienna, Austria	An additional floor has been added on the rooftop of one of the residential buildings in Vienna. The additional storey complies with Passive house measures.	- Attic is fully glazed; thermal insulations have been used and highly effective HVAC system (COP up to 5). - Passive measures have been taken in consideration such as summer night ventilation, sensible air conditioning (heating and cooling). Passive usage for energy concept and PV Panels. Active concrete slabs are used for cooling. Geothermal cooling (Brunnenkuhlung)

5	Kierling, Austria	The original house was built in 1977. The study examined alternatives to ensure that the case is executed with passive house standards and to have financial benefits. The whole projects consists of one new building, additional floor on the existing building and whole renovation for the old building and its active system to meet the Passive house Standards	- Active solar energy (Thermal and PV) have been used and a biomass heating completed for active solar house. - Glazed winter gardens were located at the south; solid wooden panels were used for the attic expansion. - Heat loss is minimized by using 20cm insulation & replaced passive windows - The heat loss at the basement was minimized by using “insulating aprons” (insulation from inside and outside).
6	Boulogne, France	A Social housing that was built in the 30s, where all the rooftops have been extended 2 more stories creating nearly 500 new apartments. The Cost per square meter reached 750 euros.	- Light steel framing and envelope has been used for the extension and mineral wool, plaster boards, glass and terracotta have been added. - The new structure was connected to the old one by a perimetrical and transverse steel beam podium. - Long vertical columns have been added along the facades in some location.
7	Kramerstraat, Rotterdam, Netherlands	Two four storey buildings in Rotterdam, dating originally from 1961, have been extended to create two new floors without having to move the occupants during the construction process. In addition, occupants are not displaced during the construction work.	- Light steel framing have been pre-fabricated and lifted into site, - Lightweight steel frame with gypsum screed flooring did not over-load the existing concrete structure. - The separating walls were pre-fabricated and are also supported by the PFC sections and use 100 mm deep light steel C sections with 2 layers of 12 mm thick fire resistant plasterboard to achieve 60 minutes fire resistance - The overall weight of the new floor and wall construction is less than 180 kg/m2
8	Husby, Sweden	The existing buildings were built during the seventies. The buildings had five floors and its structural system is site cast concrete slabs and pre-cast concrete columns. The project was extended with one-storey volumetric student study bedroom apartments.	- The modules were delivered in two parts, the roof structure and the modules. It was possible to assemble a module per day. - Light-gauge steel framing results in a light-weight building compared to one made of traditional materials

A classification has been made according to the type of structural design and installation techniques. According to the analysis that has been conducted, the structural design could be divided into two main categories; the first is by a direct framing on the roof either in timber such as the case (3) in Barcelona, or lightweight steel structure such as in the cases (7 & 8) in Rotterdam and Stockholm. The second is based on the installation technique, which is either by onsite assembly of wall and roof panels such as in the cases (4 & 5) in Vienna, or a complete assembly in the factory and then direct installation of the whole unit or half a unit onsite such as the cases of (1 & 2) in Barcelona. The direct installation of the units usually takes from one to three days for installation, and then the rest of the period is consumed for interior finishing.

However, according to that classification, there is the possibility of using a hybrid technique, which is the usage of both techniques at the same time. For instance, in the case (6) in Paris, in the reinforcement techniques, a total reinforcement from the ground and frames on the roof were used in construction. The same hybrid technique for the installation methods were found in cases (7 & 8), wall panels were assembled in site, while the roof structure was made in the factory.

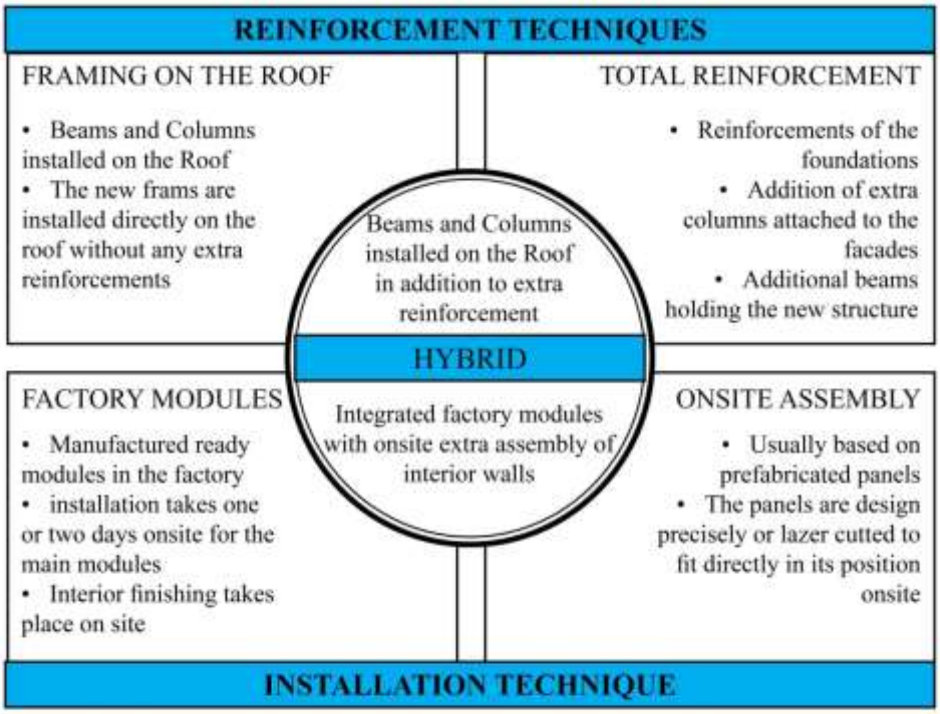

Figure 2. *Classification of main existing categories of roof stacking technologies and methods*

6. DISCUSSION

This paper is a part of an ongoing research, which aims to demonstrate validated design prototypes and products of different zero energy, timber frame construction systems and composite components. This paper represents the first step on the track of that research, focusing on reviewing previous roof stacking cases for residential building around Europe, which had the aim for increasing density in principle. Those cases have been classified according to stacking techniques and used building materials.

The availability of information is considered to be a major challenge in this research. Accordingly, the finding in this research is based and limited by the number of cases that has been reviewed. That limitation has three main consecutive reasons. First, there is no any sort of database or a defined resource where different case studies from around the world are being presented or reviewed. Second, the information about the different cases was not always available. Therefore, some cases have been excluded from the classification process.

Based on the review, it was found that there is no systematic approach or an approved methodology for roof stacking that straps all the cases together. Every case has been developed individually. However, among those cases, the projects that have been built by the Spanish architect follow do have a specific theme and methodology that has been developed specifically by the architect. That architectural office, named “La Casa Por El Tejado” that can be translated in English as “The roof house”, is devoted to this type of projects, which required from their side to develop a validated methodology that could be repeated several times.

Apart from the scientific approach for roof stacking application, there are other challenges that needed to be mentioned. The main challenges that always face roof stacking process can be defined as following:

6.1. Legislations

All cases that have been reviewed had to pass by legislative procedures, which usually can be a burden on the owner to get approval to raise the height of a building. Some cases have not faced that problem as it has initiated by the city itself in a response to a need for more apartments or residential rooms. Usually the design has to follow the local legislations such as those that require to install an elevator when a building reaches a certain height, and especially when the original building had no elevator before. The installation of the elevator considered to be an additional cost to the whole process. Another case with the buildings registered or considered as heritage building, which represents a main obstacle and can preclude from the beginning the opportunity for roof stacking.

6.2. Occupants

Knowing that roof raising has consequences in terms of, sometimes, blocking views, or inconvenience during the construction process, in some cases, the acceptance of the occupants and the neighbors can be a must to approve the project. Usually a voting process should take place before the start of the project unless the project is not located in a high dense area or does not lie under the influence of neighbors' approval.

6.3. Original structure of the building

Once the project got approved by the city regulations and possible neighbors, the structure and strength of the original building is considered as a pure technical challenge. The optimal case of raising the roof of a resilient building which has been designed to hold more than its weight is not always the case. Thus, the different methods presented in the different cases were analyzed. In some cases, extra weight on the roof, including outlet box stair, roof cover, cornices, water tanks and storages, had to be removed.

6.4. Time

In most of the cases where occupants cannot be temporary evacuated the time represents the top essences, taking in consideration the inconvenience that is being caused to those occupants. Moreover, the time challenge counts the transportation of building materials, in many cases, through busy streets, which can cause traffic and needs more permission from authorities. Thus, all week days are not always available, which limits the transportation time to weekends.

6.5. Feasibility

The feasibility of the project which counts on several factors, starting from the cost of structural solutions and building materials till the costs that are extra added to the project, such as elevator installation or extra renovation. However, it was stated in the majority of the cases that the feasibility studies for roof stacking shows the possibility to further apply full renovations for building facades to achieve higher passive standards and less energy consumptions.

6.6. Knowledge

In this research, there is no evidence for lacking of knowledge for this type of project. Yet, by the normal investigation, it is found that the knowledge and technology involved in roof stacking exceeds and differs from those exists in conventional typical architectural projects. A strong background in the field of structural engineering and lightweight construction from one side, in addition to environmental engineering from the other side is needed to be able to implement such type of projects, which is not usually the case.

This research will be further extended to include more cases to be reviewed, and probably new findings in the techniques that can be used for roof stacking and densification. In addition it will be followed by interviews with architects, site visits and investigations of further case studies.

7. Reference

United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision. New York: United Nations.

United Nations, Department of Economic and Social Affairs, Population Division (2014). World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).

Marshall J. (2007) Urban Land Area and Population Growth: A New Scaling Relationship for Metropolitan Expansion. Urban Studies, Vol. 44, No. 10, 1889– 1904

Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K. (2011.) A meta-analysis of global urban land expansion. PLoS ONE 6 (8), e23777

Angel, S., Parent, J., Civco, D. L., Blei, A. M.,(2010). The persistent decline of urban densities: Global and historical evidence of sprawl. Lincoln Institute Working Paper. Cambridge, MA.

Hutyra, L.R., Yoon, B., H-C, J., A, M., (2011). Carbon consequences of land cover change and expansion of lands: A case study in the Seattle metropolitan region. Landscape and Urban Planning 103 (1) pp.83–93

National Research Council (2009) Driving and the built environment: The effects of compact development on motorized travel, energy use, and CO2 emissions. Washington, D.C., Transportation Research Board

Brownstone, D. (2008). Key Relationships Between the Built Environment and VMT. Department of Economics, University of California, Irvine.

Gill, M., & Bhide, A. (2012). Densification through vertical resettlement as a tool for sustainable urban development. In 6th Urban Research and Knowledge Symposium. Barcelona.

Kruse, H., & Torstensson, L. (2011). Vertical extensions of the Urban Swahili house: A proposal for standardised two-storey construction.

Papageorgiou, M. (2016). Optimal Vertical Extension: A study on costs and environmental impact for structural engineers (Doctoral dissertation, TU Delft, Delft University of Technology).

Renovation of Buildings using Steel Technologies (ROBUST). Publications Office, 2013.

Reinberg, G., W. (2015). Passivhaussanierung Und Nachverdichtung, Kierling. Internationale für hochwertige Sanierung und Nachverdichtung mit Holzbausystemen. Graz, Österreich