Sustainable Cities and Society 47 (2019) 101456

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Identification of sustainable criteria for decision-making on roof stacking construction method

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ARTICLE INFO

Keywords:
Urban densification
Lightweight construction
Zero energy
Cost-optimal
Roof extension

ABSTRACT

Accommodating populations in cities became increasingly a complex task. With the mounting local and global migration seeking better opportunities in cities, the current urban agendas has put forward compact cities as a promising solution towards sustainable urban development. Roof stacking is considered an approach towards increasing cities' density. However, the selection of optimum roof stacking construction method is merely based on subjective evidence based on architects' or owners requirements. There is an urgent need to identify sustainable criteria for decision making for roof stacking. Therefore, this research aimed to identify the influential criteria behind the selection and decision making on roof stacking methods. An intensive review of literature, individual interview, and pilot surveys have been carried out. A list of 37 sustainable criteria have been identified based on sustainability triple bottom line, i.e. environmental, economic, and social. A questionnaire has been design and distributed to architects and building engineers as active stakeholders. The importance of the identified criteria have been categorized and ranked. The outcomes of this research draws the line to develop a new tool that facilitates the construction of sustainable roofs in European cities.

1. Introduction

World population increases exponentially. This increase is expected to reach 9.425 billion by the year 2050, with 32% increase equivalent to more than 2.37 billion (United Nations, 2015). Local and global migration, polarization of intellectuals either skilled labours and international students, are all factors that contribute to an inevitable increase of population, and therefore higher demand for housing especially in Europe (Bonifazi et al., 2008). New research agendas address this issue in response to the upcoming needs to accommodate increasing population while maintaining sustainable urban development and limiting urban sprawl (United Nations, 2017). Many researchers explored the implications of urban densification, which states that higher city densities support efficient infrastructure and reduces carbon emissions (Dieleman & Wegener, 2004; Gaitani et al., 2014; Nabielek, 2011; National Research Council, 2009; Skovbro, 2001). Others argue that compact forms significantly reduce the energy consumption on the building and transportation scale (Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; Madlener & Sunak, 2011; Riera Pérez & Rey, 2013; Steemers, 2003).

There are several methods followed in order to achieve higher densities in cities. Roof stacking method that has been widely taking place in the last 20 years (Amer, Reiter, & Attia, 2018). Roof stacking shows numerous benefits such as conserving vacant areas, promoting for a balance between urban densification and the preservation of green areas (Nilsson, Nielsen, Aalbers, & Bell, 2014). Moreover, it was found that applying roof stacking is more energy efficient compared to roof renovation. It was found that roof stacking reduces energy consumption by 17% more than flat roof renovation and 6% more than saddle roof renovation (Tichelmann & Groß, 2016). Marique and Reiter (2014) found that by increasing the density of a neighbourhood alone without applying retrofitting measures, a reduction up to 30% of the total energy consumption could be achieved. Despite the benefits of roof stacking, there are several drawbacks. Amer, Mustafa, Teller, Attia, and Reiter, (2017) presented a comparative analysis for different densification methods by showing the advantages and disadvantages of each method.

Very few literature attempted to classify roof stacking methods, which is designated in this research by the methods of bearing additional loads on the existing building from one hand, and the methods of assembling additional roofs from the other hand. The choice of building materials is also concerned in this study as a fundamental pillar in the decision making process. Floerke, Weiß, Stein, and Wagner, (2014) gathered a wide number of roof stacking projects around the world. Those projects were categorized according on their shapes, such as saddled shaped, cubic form, set back, free form, combined extension,

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https://doi.org/10.1016/j.scs.2019.101456
Received 11 June 2018; Received in revised form 11 October 2018; Accepted 1 February 2019
Available online 06 February 2019

Nomenclature

DMC	Decision making criteria
EPBD	Energy performance of buildings directive
HVAC	Heating, ventilation, and air conditioning
MEP	Mechanical, electrical, and pluming
nZEB	Nearly – zero energy buildings
PPMOF	Prefabrication, preassembly, modularization and offsite fabrication
RS	Roof stacking
SI	Severity index
SPC	Sustainability performance crtieria

and juxtaposed extension. Another classification was based on three aspects: the potential of realizing the project, number of added stories and percentage of roof occupation (Tichelmann & Groß, 2016). As a result, four main methods were identified: one added saddle shaped floor, one added flat roof floor, two added floors, and lastly three or more added floors. The latter classification was based on the structural performance of the existing structure.

As a first step, the decision on load bearing system is made by civil engineers based on the available information of the existing building, or by carrying on detailed assessment. Definitive constrains outline the design of loads distribution and required reinforcement such as: actual strength and structural configuration of the existing building, soil bearing capacity, wind and seismic loads, in addition to the design added weight, which define some of the constrains in deciding on the most suitable load bearing system (Papageorgiou, 2016). Detailed assessment of the actual strength and structural configurations takes by two means: non-destructive and destructive methods (Maierhofer, Reinhardt, & Dobmann, 2010; Runkiewicz, 2009). In most cases, destructive methods are combined with non-destructive methods, where characteristic compressive and tensile strength are analysed when there is no sufficient information about an existing building. Accordingly, on the first level, the decision is made on whether to add more structure or not. Afterwards proper interventions are defined by the given constrains and available budget. The decision on the type of intervention is taken by specialized civil engineers and follows systematic procedures (ISO 13822, 2010).

Roof stacking assembly method comes in the second step of the decision making process. The choice of assembly method depends on contextual settings, such as site condition, available facilities, cost and timeframe. Three methods have been generally observed for vertical extensions (Amer & Attia, 2018). In the first method, 3D modular units from the factory are installed directly on the rooftop. In highly dense urban areas, assembling 3D units is considered to be highly efficient in terms of the time needed onsite (Artés, 2016). The units takes several forms such as containers, partial and full residential units (Lawson, Ogden, & Goodier, 2014). In this method, finishing process including interior and exterior plastering, electricity outlets and sanitation always takes place onsite. Precise measurements for the roof and onsite conditions are prerequisites for a successful assembling procedure and to minimize expected errors for transportation and lifting the elements onto the rooftop. The second method of roof stacking takes place by assembling 2D prefabricated panels directly on the rooftop, such as walls, floors, ceilings and partitions (Artes, Wadel, & Marti, 2017; Reinberg, 2001; Said, Chalasani, & Logan, 2017). Assembling prefabricated panels suites architectural designs with less modularity or bigger sizes. It is also easier in terms of transportation and lifting. However, this method requires further consideration for joints design and assembly techniques (Lawson et al., 2010a). The third method takes place by assembling prefabricated *1D* individual components, such as beams and columns. This method requires more time onsite (Lawson et al., 2010b). It is possible to combine more than one method in the same project. For instance, in one of the recorded case studies, the assembly of timber frames took place in the courtyard of the building, afterwards it was installed on the rooftop as preassembled 2D panels such as a roof or a wall (Amer & Attia, 2017).

As shown previously, there are plenty of roof stacking methods. In order to achieve the desired benefits from roof stacking, right measurements and precautions have to be taken in consideration, especially during the early phase decision making procedures. There is several literature that identifies sustainability assessment measurements for new construction, renovation and neighborhoods. However, when it comes to roof stacking there is a knowledge gap in regards to the following:

I Definitive sustainability criteria for building on the rooftops, which secures the achievement of the most benefits out of roof stacking while avoiding possible drawbacks.
II Relevant studies that identify sustainable performance indicator for roof stacking methods in the European context.
III Importance of each indicator from the perspective of architects and building engineers, who play an important role in the design and decision making process.

The aim and objectives of this study address the mentioned knowledge gaps. Accordingly, the significance of this research lies in its aim to provide an approach towards sustainable construction on the rooftops. In order to achieve this aim, this research adopts three objectives. The first objective is to review sustainability criteria for prefabricated, modular, dry construction and related fields in previous literature. The second objective is to identify the influencing criteria on the process of selecting specific construction method particularly for roof stacking projects for residential buildings within the European context. The third objective is to rank the importance of each criterion in relation with other criteria in the decision making process from the perspective of architects and building engineers.

It is important to mention that there is a high frequency of incorporating a full modernization of the existing buildings on which roof stacking takes place. An overall refurbishment is inevitably accompanied with an additional complexity in the decision making process. This complexity has been addressed in several research in terms of multi-objectivity, decision-making models, till incorporating low-carbon refurbishments and energy efficiency targets (Alanne, 2004; Corrado & Ballarini, 2016; Juan, Kim, Roper, & Castro-Lacouture, 2009; Konstantinou & Knaack, 2013; Li, Ng, & Skitmore, 2018). Therefore, this research opt to focus on roof stacking related criteria to bring on an added contribution to the related research gap on roof stacking. This study is a step towards achieving a holistic sustainability for existing building and the new stacked roof.

This paper consists of seven sections. A general introduction of this article is presented in the first section, where roof stacking methods are identified by the mean of load bearing and assembling techniques. The second section introduces and illustrates the methodology of this research. In the third section, Sustainable Performance criteria (SPC) for roof stacking are identified. A review is carried out on literature and previous research work in related fields that cover modular construction and building materials resembles in PPMOF (Prefabrication, Preassembly, Modularization and Offsite Fabrication). Afterwards, a pilot survey and semi-structured interviews are carried out in this section to finalize the outcome of the developed criteria on this level. In the fourth section, questionnaire design, targeted respondents and data analysis methods are discussed and demonstrated. The results of this research are presented in the fifth section. This section includes the analysis of the respondents, questionnaire validity, and the results of the ranking analysis of the identified criteria. In the seventh and last section, the conclusion of this research is drawn, giving highlights on the strengths, limitation and recommended future work.

2. Methodology

The methodology in this paper encompasses three different phases as shown in Fig. 1. The first phase reviews the criteria that affect the decision making on choosing construction methods and the choice of building materials are being identified. An investigation has been carried out through a comprehensive review of literature. The aim was to collect articles and group them, exploring factors linked to roof stacking construction methods, and sustainable building materials. Through running a pilot survey and conducting semi-structured interviews with different architects and building engineers who are experienced with roof stacking projects. This phase aimed to identify the most influencing criteria on the decision making process and to get an in-depth overview about roof stacking projects from practical perspective.

A questionnaire in the second phase has been designed and surveyed to architects and building engineers as the stakeholders who are actively involved in the decision making process. The questionnaire has been designed in English, French and Dutch, to reach the maximum number of respondents in Europe. The questionnaire has been administered online and in a PDF format. Both methods have been used to ensure receiving a wider range of responses. The questionnaire was delivered to more than 300 individuals, and followed by two reminder emails. Moreover, researchers from the same professional field were added to the targeted respondents to support the scientific and rational contribution into the final results. The aim of this survey is to assess the importance of each indicator.

In the third and last phase of this paper, the robustness of the results are checked through reliability analysis through Cronbach's alpha. The aim of this reliability analysis is to examine the internal consistency of the results, which have been ranked through ranking analysis using Severity Index (SI). The ranking process assesses the importance of each decision making indicator in relation to the other criteria. The developed methodology in this paper adopts similar strategies that established sustainability criteria for sustainable building and construction method selection (Chen, Okudan, & Riley, 2010; Bhatt, Macwan, Bhatt, & Patel, 2010; Chen, Okudan, & Riley, 2010; Cinelli, Coles, & Kirwan, 2014; Idrus & Newman, 2002; Rid, Lammers, & Zimmermann, 2017; Soetanto, Dainty, Glass, & Price, 2006). Given the special conditions of roof stacking projects, a state of the art performance criteria have been identified that facilitates the decision making process on selecting the most sustainable roof stacking construction.

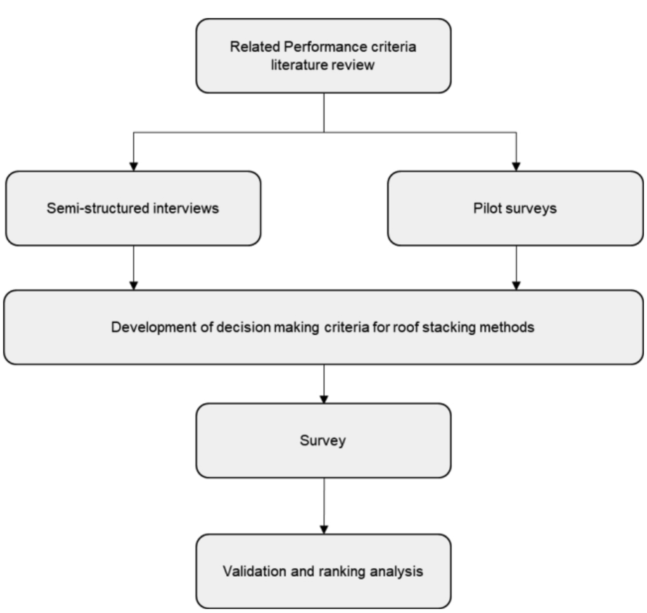

Fig. 1. Research methodology diagram.

3. Identification of sustainable performance indicators criteria (SPC)

3.1. Previous studies and related criteria

A comprehensive review of literature in related areas has been carried out. Related areas that cover assembly methods and building materials are resembled in PPMOF (Prefabrication, Preassembly, Modularization and Offsite Fabrication). Modular construction and comparisons between different construction methods and technologies are also included in the review (Said et al., 2017; Salama, Salah, Moselhi, & Al-Hussein, 2017; Yuan, Sun, & Wang, 2018).

Idrus and Newman (2002) identified 29 factors that influence the decision making of different floor construction systems. Those factors were perceived by a conducted survey for several UK construction industry professionals and were categorized under six categories, which are architectural, structural, constructional, operational, environmental, and service. The study was limited to construction related factors that counted 12 out of the 29 factors. Goodier and Gibb (2007) provided an indication the opinion of different sectors such as clients, contractors and engineers through questionnaire survey. The outcomes of the questionnaire survey were summed up into 26 weighted factors. The factors are classified as advantages and barriers of offsite construction method. One of the main critical factors of that study was skilled labours, which was critical from the perspective of the contractors and suppliers.

Another study was conducted in the U.S., where Chen et al. (2010b) adopted the same methodology. A total of 33 sustainable performance criteria have been developed for construction method selection in concrete buildings. Those criteria have been categorized based on the triple bottom line of sustainability which are: economic, social and environmental aspects. The study rated and further analysed the developed criteria through conducting a wide survey to industrial practitioners in the field of construction. Kamali and Hewage (2017) adopted the same results of the 33 sustainable performance criteria and categorized them differently under the same triple bottom line of sustainability. Jaillon and Spoon (2008) conducted a comparison between different sustainable construction aspects in dense urban environment of Hong Kong. The comparison was made on the same triple bottom line of sustainability: economic, environmental, and social aspects for 13 different categories. The comparison was based on industry questionnaire survey in addition to detailed case study analysis. Another survey in the same area comparing between different constructions methods with a focus on waste generation and management has been conducted. Tam, Tam, Zeng, and Ng, (2007) categorized 17 advantages and disadvantages of constructional aspects in the comparative analysis. Important findings related to cost and site supervision were highlighted as key factors in the whole construction process.

Legmpelos (2013) adopted a decision making method named "Choosing by Advantage" CBA to choose between three different construction methods. 19 different factors that influence the decision making were identified under 6 categories: Location, time, quality, safety, weather and project's characteristics. Even though cost criterion was not set directly as an influential factor in that study, it has been mentioned under the "hidden cost" term. Hidden cost term referred to the negative cash flows, as a result of the difficulty to predict them. Thus, the light is shed over the factors that concern hidden cost and their influence on the whole decision making process. Similar differentiation between what so called the hidden cost and major cost has been mention in another research. Blismas, Pasquire, and Gibb, (2006) showed that different case studies demonstrated the evaluation on direct material and labour cost, while disregarding other cost related items such as site facilities, crane use and rectification of works. Song, Fagerlund Walter, Haas Carl, Tatum Clyde, and Vanegas Jorge, (2005) divided the decision making process into two levels. The first level identifies the feasibility of the project, while the second level assess the construction in details, which corresponds to 10 categories. The 10 categories included time, cost, labour, safety, site attributes, contract types, design, transportation, supplier capacity, in addition to the mechanical system capacity.

As shown in the literature review, findings from the previous studies proposed several factors and criteria of decision making. In this research, criteria related to construction parameters were only selected. Other criteria related to end user satisfaction, social acceptance or local market, are not selected unless it affects the constructional process. However, due to the special conditions of roof stacking projects, further interview and pilot survey has been conducted to assess the findings and to identify further criteria that influence the decision making on roof stacking method.

3.2. Interviews and pilot survey

In order to get in-depth overview on roof stacking projects from a practical point of view, several interviews have been conducted with three architects from three different countries. The interviews were based on semi-structured questionnaire. In this type of questionnaire, each architect had the flexibility to comprehensively explain their projects. The architects were selected based on the diversity in geographical context, the type and diversity of the implemented project. Each of the previously described methods of roof stacking were used in the investigated projects. Moreover, some of the interviewed architects have experience with multiple roof stacking projects. For instance, one of the architects has implemented more than 10 cases. Throughout the interviews, it was possible to identify the criteria and process of the decision making from a practical point of view.

Afterwards, a first draft for the sustainable performance criteria have been designed based on the review of literature. However, in order to validate those criteria, a pilot survey has been distributed among 10 architects and building engineers with various backgrounds in academia and practice. The interviewees were given the task to do three things: (i) provide a feedback on the structure of the criteria and their relevance to each category that has been assigned for. (ii) Provide further suggestions and modifications on the given criteria pointing out what is relevant and what is not. (iii) Answer and review the questionnaire before launching a wide survey. The pilot survey was stopped after 10 interviewees, this is when a repetition has been found in the answers from the experts.

According to the received feedback from the pilot survey and interviews, the identified SPIs have been refined and categorized under the triple bottom line of sustainability, i.e. environmental, economic, and social as shown in Table 1. The final outcome was used to develop the final questionnaire and launching the survey, which is described in details in the following section.

4. Questionnaire design and surveying

Based on the literature review, primary criteria were developed and categorized as shown in the previous section in this paper. The criteria have been further refined and modified according to a pilot survey and individual interviews with practitioners who have expertise in roof stacking projects. Based on the identified criteria, a survey has been conducted on a broader scale. The aim of this survey is to investigate the importance of each indicator from the point of view of a wide range of practitioners.

4.1. Questionnaire design and targeted respondents

The questionnaire has been designed in three languages: English, French and Dutch. Those language were necessary to reach the maximum number of respondents around Europe and Belgium specifically. Afterwards the questionnaire has been administered in two different formats: online and PDF format. The online survey platform saved more time because it did not require a second contact between the surveyor and respondents. Yet, both methods have been used to ensure receiving a wider range of responses.

The questionnaire is divided into eight sections. The first section aimed to provide basic information about the respondent, such as their experience, number of roof stacking projects they have been involved in, and the methods used in construction. The other seven sections included the decision making criteria, in which the respondents were asked to rank the level of importance of every indicator on a scale of 1 to 5. The scale of 1 represents the least important while the scale of 5 represents the most important. Respondents were encouraged to add more criteria based on their experience and point of view. Added criteria were amended and integrated with the given list to generate more comprehensive and inclusive performance criteria for roof stacking. The definitions of the criteria were attached with the questionnaire for guidance and clarification whenever is needed by the respondent.

In this type of projects, targeted respondents or stakeholders who are concerned with roof stacking are defined under two types: active and passive stakeholders. Active stakeholders are those who actively participate in the construction process of roof stacking and selection of construction method and building materials, such as architects, engineers, and contractors. While passive stakeholders are those who are affected by the construction or the construction process of roof stacking, such as the owner and neighbours. Each type of stakeholders has different interests and priorities. Since only construction related

Table 1
Sustainability performance criteria (SPC) on roof stacking.

Economic category	Social category	Environmental category
C1: Labour Cost	S1: Workers health and safety	E1: Waste production & management
C2: Materials Cost	S2: Vandalism & loss of materials	E2: Pollution generation
C3: Transportation Cost	S3: Design flexibility & constructability	E3: Water consumption
C4: Maintenance, defects & damages	S4: Aesthetic product	E4: Circularity
C5: Life cycle & disposal	S5: Supplier availability & reliability	E5: Environmental Impact
C6: Post occupancy operational cost	S6: Availability of skilled labours	E6: Thermal mass of building materials
C7: Offsite construction time	S7: Having less labours onsite	E7: Acoustic impedance
C8: Onsite construction time	S8: Noise generation	E8: Energy consumption
C9: Coordination & transportation time	S9: Avoiding site disruption	E9: Durability
C10: Time intervals between tasks		E10: Weight of building materials
C11: Effect of weather conditions		E11: Structural capacity
C12: Quality of prefabricated elements		E12: Fire resistance
C13: Integration with building's service		
C14: Dimensional constrains		
C15: Accessibility to worksite area		
C16: Ease of management & supervision		

factors were considered in the development and ranking of decision making criteria, this research have been studied from the point of view of the active stakeholders, specifically architects.

The questionnaire has been administered in several ways. The first way was by directly sending to a contact list of architects. Those contacts have been gathered during the early investigations into roof stacking case studies. Further, the questionnaire has been indirectly distributed through building and construction institutions who were present during the Batibouw Expo, the largest building and construction exhibition in Belgium that takes place once a year hosting more than 300,000 visitors. The contacted institutions includes but limited to the architectural chamber in Belgium, both *Order des Architectes* for Wallonia region French speaking community and *Orde van Architecten* for the Dutch speaking community in Flanders. Lastly, the questionnaire has been distributed through the mailing list and social media of the academic institution represented in the University, which contains contacts of academics and researchers from the field of engineering and construction.

4.2. Data analysis methods

The main aim of this survey is to identify the level of importance of each criterion rather than quantifying the importance of the criteria between each other. In order to conduct ranking analysis for the given criteria, non-parametric statistics has been used (Johnson & Bhattacharyya, 2014) rather than parametric statistics such as means, standard deviation, etc. as it wouldn't produce meaningful results (Chen et al., 2010b; Idrus & Newman, 2002). The non-parametric analysis that has been adopted in this research is by using severity index as shown in Eq. (1).

$$\text{Severity Index (SI)} = \frac{\sum_{i=1}^{5} w_i \cdot \frac{fi}{n} \cdot 100\%}{a} \quad (1)$$

Where i represents the point given to each criterion by the respondent, which range from 1 to 5. The wi represents the weight of each criterion that takes a rating score from 1 as the lowest and 5 as the highest. fi is the frequency of the point i by all the total number of respondents that is represented by n. Finally a represents the highest weight which is equal to 5. The resulted values of the severity index may range between 0 the lowest and 1 the highest.

Reliability analysis has been further conducted to ensure that the criteria are consistent. Alpha reliability coefficient, named as Cronbach's alpha, produces a value between 0 and 1. The greater the value the more internal consistency it achieves. In order to calculate Severity Index, frequency analysis was carried out to obtain the rating percentages of every criterion. Severity Index analysis was adopted in this research to arrange the performance criteria according to their relative importance.

5. Results

5.1. Respondents analysis

The question are was delivered to a population sample of 327 individuals. A number of two follow up reminder emails have been sent to those who did not respond from the first time. As shown in Table 2, a total of 78 valid responses out of 327 calls have been received. Among those responses, 60 responses were professional architects and building engineers, whereas 18 were from building engineers from the researcher department and professors in the field of building and construction. Architects and building engineers from several European countries have contributed in this survey, with a majority responses from Belgium, Austria and Germany. Respondents' experiences varied. Around 30% of the respondents have less than 5 years' experience, 32% have more than 25 years' experience, and 38% have experience that ranges between 5 and 25 years. A pie chart visually represents the results of their experiences as shown in Fig. 2.

Table 2
Questionnaire response rate.

Contact method	Distributed questionnaires	Valid responses	Response Rate (%)
Direct emails	114	55	48%
Indirect emails	213	23	10.7%
Total	**327**	**78**	**23.8%**

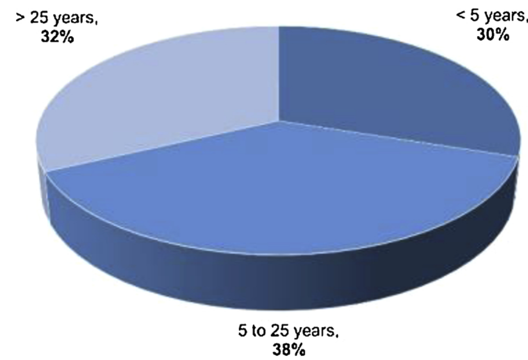

Fig. 2. Percentage of respondent's years of experience.

There have been variations in the number of roof stacking projects in which respondents have been involved. As shown in Fig. 3, about 41% have an experience of less than two projects, which means that they may have not been involved in such many projects. However, we made sure that every survey respondent has participated in at least one project. Therefore, their responses were important since they are targeted active stakeholders meant to take decision when involved in such projects. Whereas 30% of the respondents have experience with a number between 2 and 5 roof stacking projects, 17% have experience with 6 to 10 roof stacking projects, and finally 12% have experience with more than 10 roof stacking projects. When we opted to distinguish long experienced (> 25 years) and short experienced (< 5 years) participants, we did not identify a significant difference. Therefore, there was no consideration made for the difference between respondents' experiences. Even though the lack of distributing the questionnaire to more individuals from other European countries is considered a limitation to this research, the diversity in the responses in terms of country, years of experience, and involvement in roof stacking projects guarantees obtaining a holistic evaluation.

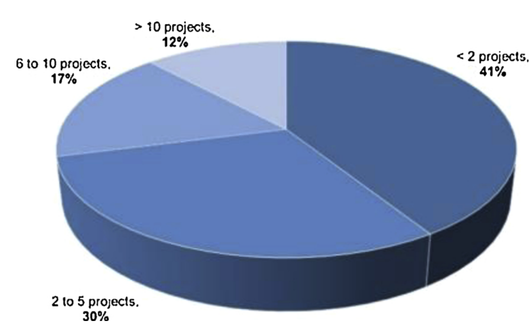

Fig. 3. Respondents experience with roof stacking projects.

5.2. Questionnaire validity

Even though the response rate has reached 23.8% from the total number of distributed questionnaire, several measurements are taken in consideration, such as sample size calculation and reliability analysis, to insure the validity of the responses. The results are measured based on a quantitative continues variables, contrary to categorical set of data. A sample size and correction formulas were calculated to determine the proper sample size using a confidence level and acceptable margin of error equivalent to 95% and 5% respectively (Bartlett, Kotrlik, & Higgins, 2001; Cochran, 1977; Kamali & Hewage, 2017). Accordingly, the total number of respondents is adequate to extract valid results.

Another test is carried out which is called reliability analysis. This analysis refers to the level to which the questionnaire produces valid results by examining its internal consistency. Reliability coefficient is determined by Cronbach's alpha, the most commonly used measurement for questions with Likert scale type of answers. Alpha reliability coefficient ranges between 0 and 1. A minimum coefficient threshold of 0.7 is required to insure internal consistency of the questionnaire (Lance, Butts, & Michels, 2006; Nunnally, 1978). The higher the value, the more consistence it is. By using SPSS statistics software, Cronbach's alpha is measure for each category as shown in Table 3. All categories achieved reliability values more than 0.8, which shows a strong internal consistency for each category and the whole questionnaire.

Table 3
Cronbach's alpha for each category.

Decision making category	Cronbach's alpha
Environmental	0.836
Economic	0.816
social	0.823
All Categories	0.871

5.3. Sustainable performance criteria (SPC) analysis and ranking

Based on the previous review of literature, together with the pilot surveys, criteria that influence the decision making process when selecting a construction methods for roof stacking have been identified and categorised under the triple bottom line of sustainability, i.e. environmental, economic, and social categories. Afterwards, a questionnaire has been distributed among professional in the field of building and construction, and those with experience in roof stacking to rank the importance of each indicator.

The results of the questionnaire have been gathered electronically and filled up in SPSS statistics software, where severity index (SI) values were calculates using Eq. (1) described under the section of data analysis method. Based on SI values, a ranking has been carried out for all criteria in a descending order as shown in Table 5. To identify the level of importance of each indicator, the range between the minimum and maximum SI values, 0.843 for the maximum value and 0.42 for the minimum value, were divided into six levels of importance as shown in Table 4:

Table 4
Evaluation levels according to severity index range.

Level	Acronym	SI range
Very High	(VH)	$0.85 > SI \geq 0.80$
High	(H)	$0.80 > SI \geq 0.70$
High Moderate	(HM)	$0.70 > SI \geq 0.65$
Moderate	(M)	$0.65 > SI \geq 0.55$
Low	(L)	$0.55 > SI \geq 0.50$
Very Low	(VL)	$0.50 > SI \geq 0.40$

Categorizing the results into six levels, three main levels in two sets each, help to set up a weighing factor for each indicator. Weighing factor does not quantify the importance difference between each indicator to the other, it rather identifies the level of importance of each indicator. The three main levels of evaluation are as following: High, Medium, and Low. While the secondary grading is given under each level to identify the indicator with the higher importance. For instance, "High" level is graded into "Very High" and "High", giving higher importance to those criteria with SI equal of more than 0.80. While "Moderate" is graded into "High Moderate" and "Moderate", and lastly the "Low" level is graded into "Low" and "Very Low" respectively.

The results of the ranking analysis are presented in Table 5. There are 6 criteria found to have the highest priority among architects with a "Very High" rank. Those criteria are followed by 9 criteria ranked as "High", 5 criteria ranked as "High Medium", 8 criteria ranked as "Medium", 7 criteria ranked as "Low", and only 2 criteria which have the lowest priority and ranked as "Very Low".

Ranking results reflect targeted respondents' priority when building on the rooftops. This is obvious as shown that quality and safety related criteria have occupied the highest priority. Quality related criteria are represented in the importance of having high quality and durable prefabricated elements. Whereas safety related criteria are represented by workers' health and safety in the first place, followed by the weight of building materials and their structural capacity. Regarding the environmental related criteria, energy consumption represents the top priority to architects and building engineers in the design process (Attia, 2016).

In contrary, there are two criteria that represented the least priority to architects, which are the water consumption, from an environmental perspective, and vandalism of building materials, from a safety perspective. The reason behind that has to do with the nature of roof stacking, which uses dry construction methods. This method does not require the usage of water onsite as a basic need in the construction process. The aspect related to "vandalism and loss of material" reflects the fact that an evidence of losing materials due to either vandalism is not common or architects did not experience vandalism as a common problem in construction, therefore it has a negligible consideration.

From the "Quality category", the first and fifth criteria are found to be "quality of prefabricated elements" and "durability" respectively, which is reasonable when evaluating the criteria from the point of view of an architect. Both criteria came as a priority to "availability of skilled labours" and "supplier availability, location & reliability" which were ranked as only "high". From the environmental category, the "energy consumption" ranked the second among all criteria, whereas "waste production and management" is found to be ranked as "High". None of the criteria from

Table 5
SPI for roof stacking construction methods and ranking analysis.

Sustainable Performance criteria (SPC)	Valid percentage for score of (%)					Severity index	Overall Ranking	Imp. Level
	1	2	3	4	5			
C12: Quality of prefabricated elements	0.0	1.7	15.0	43.3	40.0	0.843	1	VH
E8: Energy consumption	0.0	1.7	18.3	38.3	41.7	0.840	2	VH
S1: Workers health and safety	0.0	1.7	15.0	48.3	35.0	0.833	3	VH
E10: Weight of building materials	0.0	6.7	15.0	35.0	43.3	0.830	4	VH
E9: Durability	0.0	5.0	20.0	31.7	43.3	0.827	5	VH
E11: Structural capacity	0.0	1.7	20.0	43.3	35.0	0.823	6	VH
C8: Onsite construction	0.0	5.0	23.3	41.7	30.0	0.793	7	H
S6: Availability of skilled labours	0.0	0.0	25.0	56.7	18.3	0.787	8	H
S4: Aesthetic product	1.7	5.0	23.3	40.0	30.0	0.783	9	H
C1: Labour cost	0.0	5.0	30.0	41.7	23.3	0.767	10	H
E1: Waste production & management	0.0	5.0	26.7	53.3	15.0	0.757	11	H
C2: Materials cost	0.0	11.7	28.3	45.0	15.0	0.727	12	H
E5: Environmental Impact	0.0	13.3	26.7	46.7	13.3	0.720	13	H
S5: Supplier availability, location & reliability	0.0	5.0	46.7	31.7	16.7	0.720	14	H
E7: Acoustic impedance	0.0	13.3	33.3	43.3	10.0	0.700	15	H
C6: Post occupancy operational cost	5.0	8.3	36.7	43.3	6.7	0.677	16	HM
E12: Fire resistance	3.3	13.3	38.3	35.0	10.0	0.670	17	HM
C14: Dimensional constrains	1.7	23.3	36.7	16.7	21.7	0.667	18	HM
C13: Integration with existing building's service	6.7	15.0	33.3	30.0	15.0	0.663	19	HM
C15: Accessibility to worksite & storage area	0.0	18.3	45.0	25.0	11.7	0.660	20	HM
S7: Having less labours onsite	1.7	15.0	55.0	25.0	3.3	0.627	21	M
E6: Thermal mass of building materials	1.7	26.7	36.7	28.3	6.7	0.623	22	M
C11: Effect of weather conditions	5.0	23.3	38.3	26.7	6.7	0.613	23	M
S3: Design flexibility & constructability	8.3	20.0	41.7	21.7	8.3	0.603	24	M
E4: Circularity	10.0	23.3	38.3	20.0	8.3	0.587	25	M
C10: Time intervals between tasks	5.0	30.0	41.7	18.3	5.0	0.577	26	M
C3: Transportation cost	3.3	35.0	43.3	15.0	3.3	0.560	27	M
C5: Life cycle & disposal cost	11.7	28.3	30.0	28.3	1.7	0.560	28	M
S9: Avoiding site disruption	3.3	36.7	41.7	15.0	3.3	0.557	29	L
E2: Pollution generation	5.0	35.0	40.0	16.7	3.3	0.557	30	L
C9: Coordination & transportation time	6.7	31.7	43.3	15.0	3.3	0.553	31	L
C4: Maintenance, defects & damages	13.3	28.3	38.3	16.7	3.3	0.537	32	L
C16: Ease of site management & supervision	15.0	33.3	31.7	8.3	11.7	0.537	33	L
S8: Noise generation	8.3	33.3	45.0	11.7	1.7	0.530	34	L
C7: offsite construction time	13.3	41.7	26.7	8.3	10.0	0.520	35	L
E3: Water consumption	26.7	26.7	30.0	11.7	5.0	0.483	36	VL
S2: Vandalism & loss of materials	33.3	30.0	30.0	6.7	0.0	0.420	37	VL

the cost category are ranked as "Very High". Only "labour" and "materials cost" are ranked as "High". The budget does not represent the major concern by architects, which is different from the owner or the manufacturer. However, they were still ranked as "High" since they represent a major limitation in the overall design and construction.

5.3.1. Cost and time factors

Cost has been a common project driver for the selection process of construction methods and building materials. The cost associated with transportation and lifting, maintenance, lifecycle and post occupancy are added to the cost related concerns in the decision making process, which raises the cost per unit area between 5–20% compared to onsite construction methods (Hsieh, 1997). However, not all cost related criteria possess the same importance. As shown in Fig. 4, labour cost has the highest priority followed by the cost of building materials, which are ranked as "High". However, when compared to the other criteria, they do not possess the highest priority to architects. This is due to the fact that cost represents a higher concern to clients who owns the budget and contractors or manufacturers who provides the materials and labours as proven by previous research (Chen et al., 2010b; Idrus & Newman, 2002; Kamali & Hewage, 2017). Accordingly, the given high priority for building materials and labour costs are mainly driven from clients' demand on having the highest quality with lower prices (Amer & Attia, 2017).

The cost related to post occupancy operation represents the third priority in the cost category, which is strongly linked to the indoor thermal and energy performance of the building (Attia, 2018). Post occupancy associated cost is an indicator of the environmental quality of the given design configurations, therefore it represents a "High Medium" importance to the architects. Whereas the costs associated with transportation, life cycle and maintenance got the least priority in the cost category. Given that transportation cost only may contribute up to a 15% increase in the overall cost of construction (Hsieh, 1997), there are several reasons that explains why transportation cost has not been given a high priority when choosing construction method. The first reason is related to the scale of the targeted projects, which are non-complex residential projects, do not highly causes a variation in the transportation cost and therefore the overall construction cost. Small scale projects do not require additional number of truckloads used for building materials delivery or special cranes for lifting up heavy materials. These conditions do not comply with transporting 3D modules, which requires from one hand advanced delivery and lifting settings, but on the other hand it significantly reduces the cost associated with time consumption and multiple transportation (Amer & Attia, 2017; Artes et al., 2017; Sturm et al., 2017). The second reason is because transportation cost lies under the hidden costs (Legmpelos, 2013). Hidden costs are hard to be predicted in the overall cost estimations for small projects, and that explains why transportation cost are not strongly considered in roof stacking decision making process. The same reason applies for lifecycle and maintenance costs, which are associated with a high level of uncertainty (Blismas et al., 2006; Goodier & Gibb, 2007).

The importance of time related criteria varies from one project. The variance depends on clients' requirement on the first phase followed by the method of construction. For instance, the assembly of 3D modules have shown the highest efficiency when it comes to required onsite construction time (Amer & Attia, 2017; Artes et al., 2017). Moreover, the speed of construction has a direct effect on the cost (Jaillon & Poon, 2008). This importance is obvious in the ranking analysis in the time category as shown in Fig. 4. Among time related criteria, onsite construction time is found to have the highest priority to architects in the decision making process given a "High" ranking. Associated tasks that adds to the overall construction time such as the effect of weather conditions, time intervals between different tasks, coordination and transportation time range between being "High Medium" and "Medium". Whereas the time needed for pre-construction phase does not resemble a priority to the architects. Previous research found that appropriate periods of coordination between different stakeholders such as architects, contractors, and suppliers are necessary to achieve a high quality end product (Chen et al., 2010b), which resembles the highest priority of an architect. Accordingly, the overall time related criteria has the least priority as an average compared to other categories.

5.3.2. Safety and quality factors

In this category, three aspects are considered. The first aspect consider workers' safety from dangerous tasks and, for instance, the usage of toxic materials. The second aspect consider the safety of occupants by providing a safe construction. The third aspect is related to security in construction site from vandalism. As shown in Fig. 4, three criteria out of five where ranked as "Very High" in the safety category, which are workers' health and safety, weight of building materials, and their structural capacity. Even though workers' safety and health does not lie directly under the responsibilities of architects, it has been identified as a top priority. In contrary with previous research, workers' health and safety did not occupy high importance. The interpretation of this finding is related to the actual risk that workers' have on site. Risk analysis and safety instructions lie fully under the responsibility of contractors. Given that workers' safety is a top priority, conventional construction process does not include dangerous tasks that require special consideration in the decision making process. Therefore in practice, unless construction process includes dangerous tasks, workers' safety would not influence the selection process of construction method. Whereas the selection of building materials and structural design strongly lies within the hands of the architects. Since roof stacking projects counts on the capacity of the existing building to hold more weight, total weigh of construction is very important (Amer et al., 2017; Tichelmann & Groß, 2016). Structural design represents a common challenge for roof stacking projects. Accordingly, the weight of building materials and their structural capacity are ranked as "Very High" and affects the construction method selection process.

Fire resistance is ranked as "Medium High" after the structural capacity of building materials. Interviews with architects revealed that they follow well known solution to increase the fire resistance of building materials by coating, cladding or increasing elements section in case of timber construction. Moreover, firefighting measures has strict specifications by local and Euro codes that has to be followed for each project, therefore it does not severely interfere in the decision making process. The last and least important of all criteria were found to be the vandalism of building materials, which has been given a "Very Low" priority.

Quality related criteria were found to have the average highest priority to architects when selecting construction methods for roof stacking. The quality of the prefabricated building elements and their durability possess "Very High" rank, followed by acquiring aesthetic product which is ranked as "High". Fortunately, it is easier to achieve high quality building materials in this type of construction compared to conventional onsite construction, since roof stacking relies on the usage of prefabricated building elements. The usage of prefabricated elements have several advantages given the climate-controlled environment where prefabrication is taking place. Moreover prefabrication plants have stricter quality control measures than that of the onsite construction (Jaillon & Poon, 2008; Jaillon, Poon, & Chiang, 2009). These conditions secures less damages, defects and associated disposal costs, which comes in favour of all stakeholders.

The quality in terms of integrating with existing building's services got a "High Medium" priority, while design flexibility and constructability got a "Medium" priority. Through interviews, it has found that those criteria do not resemble a great challenge in most projects. Integration of roof extensions to existing buildings does not highly influence the choice of construction method, it rather requires higher consideration for MEP and HVAC engineers.

5.3.3. Environmental and logistical factors

The importance of the environmental criteria is strongly attached to the level of awareness and responsibility towards global warming, greenhouse gases and overall environmental impact from one hand, and the onsite and indoor impact from the other hand. As shown in Fig. 4, the highest priority is given to the energy consumption among the environmental related criteria with a "Very High" ranking, and has got the second priority to the overall ranking analysis. Energy consumption is followed by waste production and management, environmental impact, and acoustic impedance with a "High" level of importance. Afterwards thermal mass and circularity of building materials are given "Medium" level of importance. Onsite pollution and noise generation are given "Low" importance, while water consumption got "Very Low" importance and lies in the bottom of the ranking analysis.

The reason behind the importance of achieving energy efficient buildings returns back to the new regulations enforced by the EU that requires all new construction should be nearly Zero Energy Buildings (nZEB) according to the Energy Performance of Building Directive (EPBD) (Boermans et al., 2015). Therefore, the majority of the architects have rated the energy consumption within their highest priorities. Energy efficient buildings are achieved by either delegating the calculation to specialized consultancies, or by simply following local codes and regulations that secures a minimum energy consumption per square meter. This finding contrasts with previous research, in which energy efficiency in buildings and energy consumption did not achieve high ranks. The main reason behind this contradiction is a result of the difference in the targeted respondents (Kamali & Hewage, 2017) or the date in which the survey was carried out (Chen et al., 2010b).

In total, there are 9 criteria that are strongly related to the selection of building materials within the assembly methods determination. The criteria are listed as following:

- (C12) Quality of prefabricated elements SI: 0.84 "Very High"
- (E10) Weight of building materials SI: 0.83 "Very High"
- (E11) Structural Capacity SI: 0.82 "Very High"
- (C2) Material cost SI: 0.73 "High"
- (E5) Environmental Impact (of materials) SI: 0.72 "High"
- (E7) Acoustic impedance SI: 0.70 "High"
- (E12) Fire resistance SI: 0.67 "Very Moderate"
- (E6) Thermal mass of building materials SI: 0.62 "Moderate"
- (E4) Circularity SI: 0.59 "Moderate"

It has been found that the quality of the building materials, followed by their weigh and structural capacity are the most important criteria that affects the decision making process when choosing building materials. Cost, environmental impact, acoustic impedance, as well as onsite waste production, come on the second level of importance, and were found to be with high importance in the selection process of construction methods and building materials. Given that prefabricated elements are used in the construction, waste levels could be reduced by 65% and up to 70% compared to conventional onsite construction methods (Jaillon et al., 2009). Moreover, materials conservation could be achieved with savings that reaches up to 70% when using timber construction (Yee, 2001), not to mention the carbon neutrality of timber as building material, which contributes in reducing the carbon emissions and have less environmental impact (Dodoo, Gustavsson, & Sathre, 2014; Ramage et al., 2017). This explains why sometimes unfavourable building materials in terms of carbon emissions, such as plastic derived materials with high quality specifications in terms of weight or structural capacity, are used in a construction site for roof stacking.

The importance of acoustic impedance is related to achieving high indoor comfort levels. In roof stacking projects, lightweight construction materials are commonly used, which has by default poor acoustic performance. Therefore, achieving acoustic impedance is highly important for architects. Even though fire resistance is essential for roof stacking, as well as conventional buildings, it was not given relatively high importance in the decision making. The reason behind that returns back to the ease of dealing with fire resistance in materials, which does not represent a high concern compared to acoustic impedance for example. Finally, thermal mass and circularity does not strongly influence the selection process of building materials.

As a consequence of using dry construction, pollution and noise are significantly avoided compared to conventional onsite construction, therefore they do not significantly influence the selection process and given a low priority in the decision making process. The same applies for water consumption, which is not strongly required in the construction process. In contrast with environmental related criteria, none of the logistics related criteria are given a very high priority. However, two criteria are ranked as "High", which are the availability of skilled labour, and supplier's location and reliability. Then followed by the dimensional constrains and accessibility to work site as "High Medium". Having less labour onsite is ranked with "Medium" importance, and lastly avoiding site interruption and ease of management are ranked with "Low" importance in the decision making process.

The ranking analysis of the logistical category reflects the share of responsibility that lies under the architect. The first two criteria strongly affects the selection of construction methods, which lies within the responsibility of the architect to find a reliable supplier. The responsibility of the second two criteria are shared by the architect, contractor or supplier, in securing reasonable dimensions of

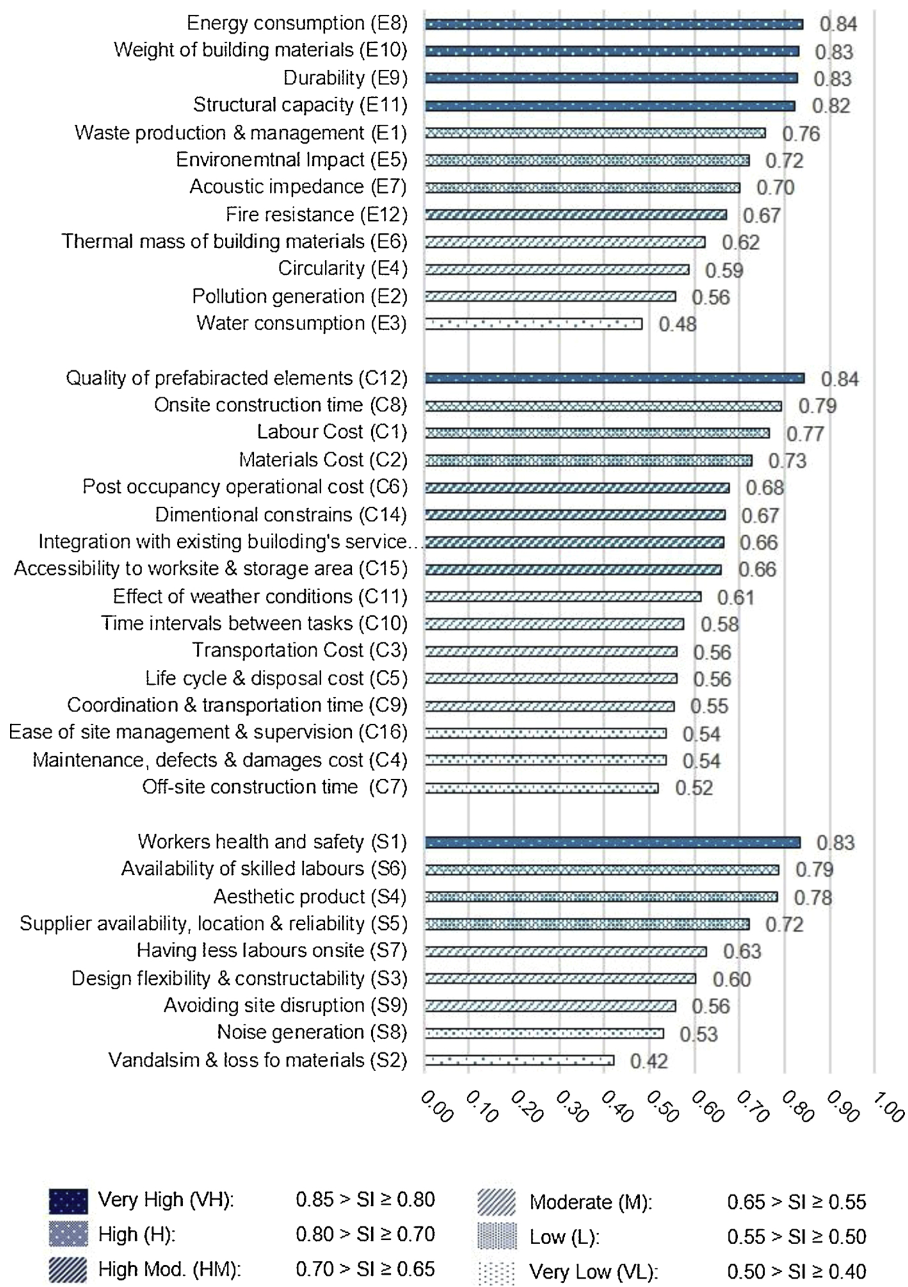

Fig. 4. Ranking analysis by category in descending order.

prefabricated elements used in construction and consequently the accessibility to worksite. The responsibility of the onsite construction process lies under the contractor, which includes labours onsite, sire disruption and overall management. Thus, they are less considered in the decision making process by architects when choosing construction methods or building materials.

6. Findings and discussion

6.1. Summary of main findings

Throughout the results of the ranking analysis, priorities given from the point of view of the architects were very significant. That's why criteria related to quality, buildings safety, and logistics categories are found in the beginning of the ranking analysis as shown in Fig. 5. Accordingly, if the targeted respondents is changed, such as contractors or clients, the final results would definitely change. This is obvious in previous research, in which cost and time related criteria were set as a priority (Chen et al., 2010b; Kamali & Hewage, 2017). criteria related to the safety of workers is common in the outcome of this research and previous research. Even though the responsibility of workers health and safety lies within the contractor's responsibility, it represents a high concern for all parties. From another perspective, the results reveal important criteria . The overseen direct relation between the thermal mass of building materials and the overall energy consumption is not evident. This issue reveals practitioners' point of view on building physics and its direct relation to the overall thermal and energetic performance of the building. In other words, reducing energy consumption may be seen to be approached by adding more insulation or photovoltaic panels. Similar point to be mentioned is the relation between post-occupancy cost and energy consumption. The tendency to consider energy consumption seemed to be a certain quality that practitioners aim to achieve. This aim was not directly related to the cost, given that achieving energy efficient building requires higher initial cost, as much as being a targeted value.

buildings worldwide. Moreover, they have been more specialized to include various types of buildings such as new buildings, homes, or even on the scale of neighborhoods. However, none of those rating systems were concerned with roof stacking. Therefore, it was a motivation to explore this type of buildings aiming to define the boundaries related to roof stacking as an approach towards more sustainable roof construction.

On one hand, there are some similarities between roof stacking SPIs and green rating systems. For instance, DGNB uses the triple bottom lines of sustainability, economic, social, and environmental, in addition to other criteria related to technical and process qualities. Moreover, some criteria in the roof stacking SPIs are found the green rating systems such as those related to cost (material, transportation, maintenance, and life cycle cost), or impact on the environmental (GHG, waste, pollution, and noise generation), or indoor quality (durability and acoustic performance).

On the other hand, it is not possible to put roof stacking SPIs side by side with green rating systems due several reasons. First, green rating systems aim to assess building's performance, whereas the roof stacking SPIs for roof stacking aim to provide a sustainable approach towards selecting the most suitable construction method for roof stacking. Second, green rating systems are highly based on quantitative and measurable aspects that are translated into a scoring system. Roof stacking KPIs are based on qualitative and quantitative aspects. For example, building material's weight, structural aspects, cost, or environmental impact could all be measures and objectively assessed. While aesthetics, ease of management, required time onsite, or number of labours onsite are either qualitative or subjective measures. Every roof stacking project's requirement is different from the other, and what suits one project could be a disadvantage for another.

Several advantages are found in the developed roof stacking SPIs when compared to green rating systems. For instance, even though DGNB is one of the first to integrate the concept of circularity in its system, under several criteria, circularity is only considered as an added value to the project without any obligation or added points to the

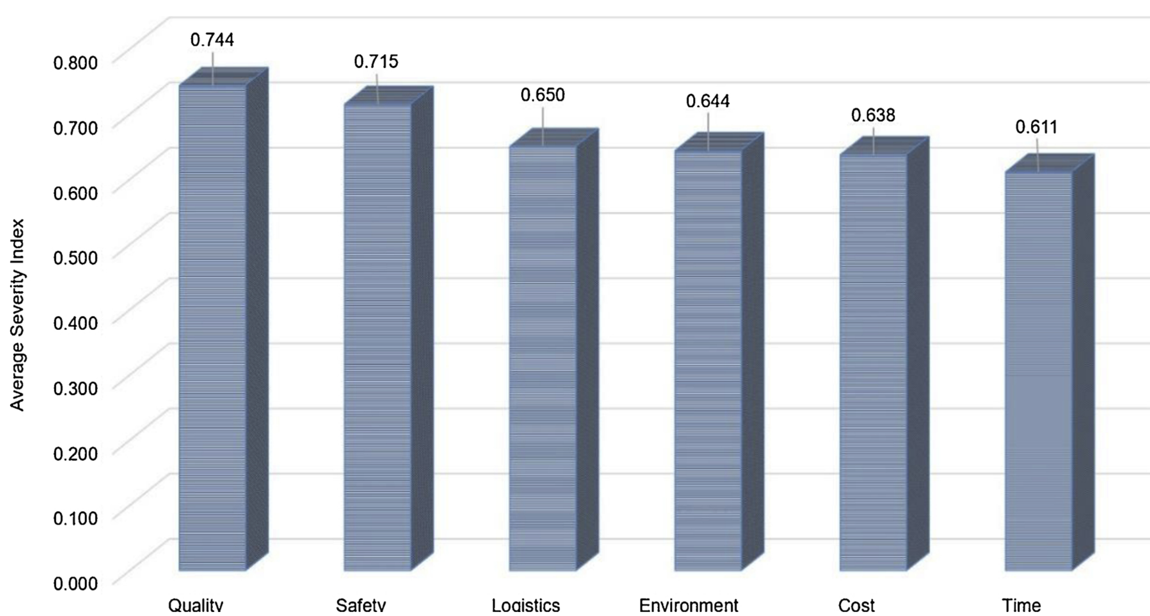

Fig. 5. Average severity index by category.

6.2. Roof stacking sustainable performance indicators (SPI) and green buildings ratings

Green buildings rating systems, such as LEED, BREEAM, or DGNB, have been developed as a motivation towards creating more sustainable

overall score. Moreover, safety during construction has not been clearly considered in the green rating systems. Safety has only been considered from the perspective of the impact of building materials on the indoor air quality and avoiding hazardous materials to occupants and environment. Last but not the least, logistical and time constraints have found to be out of the scope of the green rating system, whereas they resemble fundamental criteria when building on the rooftops of existing inhabitable buildings.

6.3. Strengths and limitations

The state of the art in this research is given in three main points. The first point is related to the nature of the project that is being investigated. Very few literature is related to roof stacking has been found, and none was found that is related to the decision making process for residential building roof stacking. Thus, a thorough review has been carried out on literature related to sustainable and modular construction. Additionally, several site visits, interviews, and pilot surveys were carried out. As an outcome, we found key criteria, which ranked as "Very High" in importance and have not been discussed before, such as the weight of building materials, structural capacity, circularity, and energy consumption. The second point is related to the context of this research. Previous related literature was carried out within different geographical context. Thus, the relative importance of the previously developed criteria would highly vary due to several reasons, such as finance and the overall culture of construction. In this article, we focus on the European context since roof stacking and the need to increase the densities of the existing cities is an important topic in Europe. This importance is due to several reasons related to the age of the existing cities, geographical context and the availability of open regional territories, which differs from other continents or countries. The third point concerned with the strength of this research is related to the targeted respondents. In previous related literature, targeted respondents were contractors, manufacturers, and engineering companies. Whereas in this research, architects and engineers who are in charge of the design and construction, are selected as the targeted respondents. The reason behind this choice is due to their role in the decision making. The final outcome highly relies on architects since as they are usually the mediators between the owner and contractor, who holds the responsibility of providing the desired quality required by the owners.

Even though the context of research and targeted audience represents a strength to this research, there are some limitation that lies within. The first limitation has to do with the type of investigated projects, which were concerned with residential buildings. The difference between raising the rooftop of a residential and any other building, such as an office building, lies in the added restrictions associated with residential buildings. Many case studies from those that have been investigated in this research, as well as the majority of the residential building in European cities, were built before 1945 (Amer & Attia, 2017; Floerke et al., 2014; Moran, 2015; Sturm et al., 2017; Van de Voorde, Bertels, & Wouters, 2015). Those buildings have more concerns in terms of structural capacity and building strength, which requires more attention in terms of overall added weight. Another thing has to do with the fact that residents may be occupying the building during construction phase. This fact puts additional stress on the time required for the onsite construction phase. Thus, the final results highly reflects the type of building, which may differ by investigating another cases.

6.4. Future work

The targeted respondents and geographical context are added to the limitation of this research. Thus, there is a huge tendency of getting different results by changing either context or respondents. This point raises a recommended for future research work. The questionnaire is recommended to be carried out for other targeted respondents, once for contractors and manufactures, and other for end users represented in the owners. By including different stakeholder in the process of assessment, a generic criteria could be developed and further be adopted as common platform between architects, owners, and legislative institutions as a in the cities to help getting approval from the city administration to raise residential rooftops. Lastly, further research, which is currently begin carried out, is needed to compare between different roof stacking methods that has been demonstrated in the literature review of this article. This analysis would help providing a scientific analysis for different types of prefabricated construction with the purpose to be used in roof stacking.

7. Conclusion

Roof stacking projects have been widely witnessed around European cities. This increase reflects by one mean the need for more living space inside the cities. Roof stacking, as a sort of structure, highly depends on dry construction methods, which depends on some off-site operations, usage of prefabricated elements and modularity in design and construction. Technologies are continuously advancing in those fields, offering more advantages for high quality end products and flexibility for the design and construction process. Given the vast diversity in building materials and construction methods, there is a lack of performance assessment criteria for roof stacking projects, especially with the additional aspects and requirements that are involved in the decision making process.

We are not aware of any conducted study that identify the criteria involved in the selection of roof stacking construction methods. Accordingly, this research identifies 37 sustainable performance criteria under the triple bottom line of sustainability, i.e. environmental, economic, and social. First, an extensive literature review on related research fields. This review has been followed by pilot survey and semi-structured interviews with architects who have experience with roof stacking projects to refine and precisely identity the influential criteria on the decision making process when raising the roof of residential buildings. The results are based within European context. Pilot survey and interviews were carried out with architects from several countries in Europe. Identified criteria have been ranked according to their importance into six evaluation levels starting from "Very High" till "Very Low". The ranking process was carried out using severity index.

Based on that classification scale, six criteria were ranked "Very High". Those criteria were highly oriented towards safety measures, such as weight and structural capacity of the building materials, in addition to workers health and safety onsite. Then two criteria from the quality measures takes place resembled in the quality of the prefabricated building elements and their durability. Finally the criterion of the energy consumption from the environmental measures were found to achieve a high level of importance by the architects in the decision making process. Whereas two criteria were found to have a "Very Low" importance, which are the onsite water consumption, and the loss or vandalism of building materials. The survey have been validated by sample size and reliability analysis to ensure the accountability of the developed criteria and final results. The final results provide an approach towards sustainable construction on the rooftops through prioritization of decision making criteria. This prioritization ensures a maximum performance with a minimum information available during early design phases. Finally, there is a great potential in European cities to increase their density through sustainable vertical extension on the existing buildings. To ensure a successful densification process, roof stacking sustainable criteria should be well integrated within the existing regulations of urban and construction.

Acknowledgements

This research was funded by a welcome grant provided by Liege University, which are gratefully acknowledged. This publication is part of the research project 2016–2020 entitled: DenCity Prototype: Concepts of Zero Energy Lightweight Construction Households for Urban Densification. Thanks are due to all the interviewed and non-interviewed architects for their feedbacks and contribution in the questionnaire survey.

Appendix A. Sustainable Performance criteria (SPC) descriptions

See Tables A1–A3

Table A1
Economic category SPCs description.

Economic category SPI	Description
C1: Labour Cost	The cost of skilled labours, supervisors, site managers, etc.
C2: Materials Cost	The cost of building materials
C3: Transportation Cost	The cost of transporting materials to the site and loading on the rooftop
C4: Maintenance, defects & damages	The cost of maintenance or damages onsite
C5: Life cycle & disposal	The cost associated with demolition and waste treatment
C6: Post occupancy operational cost	E.g. the cost needed for heating, cooling and lighting
C7: Offsite construction time	Preconstruction phase including planning, designing, and manufacturing
C8: Onsite construction time	The time needed to accomplish construction onsite
C9: Coordination & transportation time	The time consumed in coordination and transporting building materials
C10: Time intervals between tasks	The time needed for every task and the transition period between tasks
C11: Effect of weather conditions	Possible interruptions in the construction process due to weather
C12: Quality of prefabricated elements	The quality of building elements and outcome
C13: Integration with building's service	Integrating new construction with building's services & HVAC system
C14: Dimensional constrains	E.g. street widths, urban context, building's height and neighbouring buildings
C15: Accessibility to worksite area	Access to the site including lifting process and storing building materials
C16: Ease of management & supervision	Construction management and work flow process

Table A2
Social category SPCs description.

Social category	Description
S1: Workers health and safety	The risk of injury in dangerous situations during construction
S2: Vandalism & loss of materials	The probability of losing materials onsite
S3: Design flexibility & constructability	Ease of construction and applying modifications on site
S4: Aesthetic product	The quality of the final architectural product and finishing
S5: Supplier availability & reliability	Reliable supplier for building materials or offsite construction products
S6: Availability of skilled labours	The demand of skilled labour including supervisors and site managers
S7: Having less labours onsite	Unnecessary added tasks during construction
S8: Noise generation	Neighbours disturbance and causing noise
S9: Avoiding site disruption	Impact of construction activities on surrounding neighbours and traffic

Table A3
Environmental category SPCs description.

Environmental category	Description
E1: Waste production & management	The amount of wasted materials leftover during and after construction
E2: Pollution generation	CO2 emissions and dust generation during construction
E3: Water consumption	The amount of water needed onsite for construction
E4: Circularity	The opportunity to reuse building elements in other construction
E5: Environmental Impact	Building materials' impact on the environment (e.g. GHG & embodied energy)
E6: Thermal mass of building materials	The tendency of the building material to store heat
E7: Acoustic impedance	The resistance of building materials to sound
E8: Energy consumption	Energy consumed by the end user inhabitant
E9: Durability	The long usability of building elements and the whole construction
E10: Weight of building materials	Building materials weight (e.g. Kg/m2) related to structural safety
E11: Structural capacity	The structural characteristics (tension, compression, shear, etc.)
E12: Fire resistance	The resistance of building materials to fire

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