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Main perceived barriers for the development of building service integrated facades: Results from an exploratory expert survey

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A B S T R A C T

The integration of decentralised building services into façade components presents advantages from functional and constructional standpoints. However, this integrated approach has not been massively implemented, having only stand-alone buildings and façade concepts as examples. This paper seeks to identify the main perceived problems at design, production and assembly stages of the facade development process, to generate new knowledge based on practical experience; and to discuss the perceived barriers to overcome in order to promote widespread building service integration in façade systems. The employed method was an exploratory survey addressed to professionals with practical experience in the development of façade systems for office buildings, situated at any stage of the process. The survey was conducted from mid-September to mid-November 2015 and was distributed both as an online form and in printed format among several professional and research networks related with façade design and construction. After the campaign, 133 questionnaires were received, comprising a final number of 79 valid questionnaires. Results show that the main problems of the overall process are related to coordination issues among different disciplines and stakeholders, while other problems such as costs and lack of knowledge have more impact on particular stages within the design and construction process.

1. Introduction

The building industry is facing relevant challenges in the current agenda towards sustainability. On the one hand, more strict building codes and regulations are being enforced in an effort to decrease current energy consumption levels, as evidenced by the request for all buildings in the EU to consume 'nearly zero' energy after 2020 [1]. This of course impacts the overall design of new buildings, but also considers particular challenges for the building façade, as the filtering layer between outside and inside conditions [2], pushing for the application of climate responsive façade systems on both new and refurbishment projects. On the other hand, the construction industry itself has been criticised by its poor performance and outdated craft-based production methods [3,4], besides the environmental impact associated with common construction processes and building related activities [5,6]. Therefore, not only there is a need for new performance driven façade products, but also new production processes that ensure high quality results and an efficient use of resources throughout the entire life cycle of the product.

The façade industry has responded to these challenges by promoting the development of multifunctional building components, striving for a more efficient use of available resources. Hence, besides basic protective functions, also regulatory functions have been considered in the design of building envelopes to mediate between interior comfort requirements and exterior stimuli, by means of integrating supplementary measures and supplementary building services [2]. Supplementary measures refer to the use of constructive elements such as sun shading systems or extra thermal insulation, to cope with comfort requirements using nearly zero extra energy. In some cases, a small amount of energy is needed for movable mechanical components, to improve the performance of the system allowing for dynamic responses in intelligent, advanced, or climate adaptive building envelopes [7–11]. The most common façade concepts in this regard are related to the development of double-skin facades considering different combinations of layers, static or fixed building elements and multiple ventilation modes [12,13].

The integration of supplementary building services into the façade has been promoted as a next step, if the aforementioned measures are not enough to meet indoor requirements, exploiting the possibility to include extra functions under standardised manufacturing processes

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based on prefabrication. Hence, besides providing daylight, heat or noise protection; façade components may integrate active heating, ventilation and air-conditioning systems (HVAC), artificial lighting, energy storage, and even energy generation through photovoltaic panels or solar thermal collectors. These façade concepts have been discussed in the literature as 'decentralised façade services', 'service integrated facades', or simply 'integrated facades' [2,10,14], presenting benefits on several fronts ranging from users' comfort to cost savings for the main stockholders. The present article focuses on these 'integrated façades', understanding them as a specific product within the development of high-performance building envelopes.

Daniels [15] addressed the benefits derived from integration when discussing design and construction of building services, focusing on potential cost and energy savings associated with the application of integrated planning concepts. Moreover, the flexibility and local control associated with decentralised units mean potential improvements in the perceived indoor comfort and a more efficient energy usage by identifying local demands [16]. Similarly, Knaack et al. [10] supported advantages from a constructional point of view, stating that the industrial manufacturing of integrated façade modules could decrease building times during assembly stages, while limiting the occurrence of construction mistakes on site by dealing with prefabricated components. Furthermore, decentralised units do not need distribution systems nor space for large equipment, which generates more leasable floor area for any given commercial building [17].

Regardless of the mentioned advantages, this integrated approach has not been massively implemented, having stand-alone examples instead of understanding it as a promising path to follow for the development of high-performance buildings. Besides the development of façade concepts such as TE,motion, E^2, and SmartBox, from Wicona, Schueco, and ECN respectively [18–20], built examples such as Capricorn Haus in Dusseldorf, and Post Tower in Bonn (Fig. 1) have been recognised by their sustainable features, demonstrating the environmental potential of technically integrated buildings [21,22].

The main goal of this paper is to identify and discuss perceived barriers for the integration of building services in façade systems, as a way to promote the application of new cost-effective multifunctional façade products for high-performance office buildings. The method chosen for this was an exploratory survey addressed to professionals with practical experience in the development of façade systems for office buildings, situated at any stage of the design and construction process. Hence, the information gathered by the survey relies on empirical knowledge, adding new insights to previous experiences in the subject. It is important to point out that the research centred around perceived problems based on practical experience, considering the role of perception in decision-making processes related to façade design and development.

Several authors have discussed barriers for integration of building services, with focuses ranging from potential introduction into specific markets to the integration of particular active systems into the façade such as decentralised ventilation units or solar components for energy generation. Haase et al. [23] declared a series of issues that need to be addressed for the development of advanced integrated facades, considering the application of 'reactive building elements' together with building services. The authors mentioned aesthetics, functionality, economy (initial and operational) and flexibility as relevant issues for integration, without delving into details. Ledbetter [24] stated problems during the design stage of façade systems while discussing the need for holistic design of building services and façades. In general terms, he discussed the lack of knowledge of designers and the limited action of specialists during early design stages. Furthermore, he described problems indirectly caused by the package separation of components, such as responsibilities for interfaces between components, warranties in case of malfunction, or lack of feedback between contractors. Even though some technical issues such as air leakage and heat transfer were also mentioned, the attention given to aspects related to the design process itself was far greater in the paper, highlighting their relevance.

The perceived importance of barriers related to the design process was shared by Klein [22]. As part of his doctoral dissertation, Klein conducted a limited series of in-depth interviews in order to characterise the façade construction process and determine driving factors and barriers for innovation. Fifteen professionals with practical experience in façades were interviewed, considering designers, consultants, system suppliers, developers and façade builders. Regarding building services integration, it was found that decisions about the contracting strategy are essential, defining the roles and influence of the involved parties beforehand. Furthermore, the responses showed that internal processes for each party are rather optimised, so a successful project does not depend on the ability of individual stakeholders, but on their coordination and interaction during the design and construction process [22].

Zelenay et al. [25] also used interviews with experts as the main source of information to identify design strategies and practical considerations for the development of high-performance facades in general, focusing on barriers for implementation in the U.S. Around forty professionals from North America and Northern Europe were interviewed, counting architects, façade and energy consultants, researchers, manufacturers and building managers. The study identified particular barriers related to different stages of the development process: design,

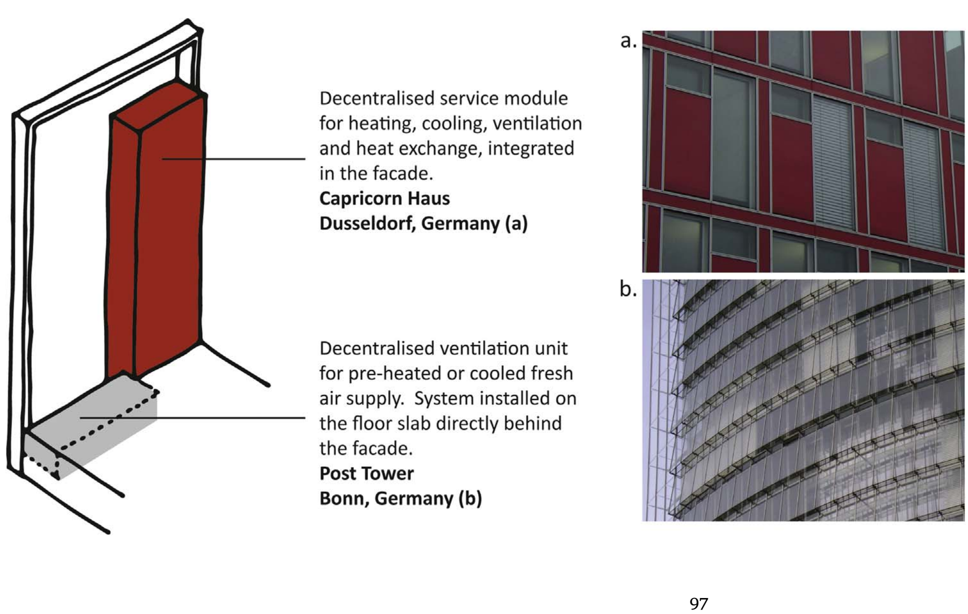

Fig. 1. Integrated façades: Capricorn Haus, Dusseldorf (a) and Post Tower, Bonn (b). Pictures from the authors.

construction and operation. Firstly, during the design stage, it was found that additional risk for the involved professionals, client acceptance and economic issues (higher design fees, construction costs and few incentives) present the main barriers to overcome. Barriers during construction stage were focused on the need for properly trained installers and several undeclared installation issues. Finally, issues discussed during operation were the cost-effectiveness of systems, continuous performance, and the need for monitoring and maintenance activities to assure occupant comfort over time [25].

Besides the discussed examples, the application of surveys has been used as a valuable tool to evaluate possibilities for façade integration of particular technologies such as decentralised ventilation units, or building integrated solar thermal panels (BIST). Operational issues related to the use of decentralised ventilation units were discussed by Mahler and Himmler [16] as a result of a monitoring campaign conducted in ten buildings. It was found that the maintenance effort for these technologies was about 2–3 times higher compared to centralised ventilation systems. Nevertheless, the reported satisfaction of the users was high, being rated either 'good' or 'very good' by 75% of the surveyed building managers. Cappel et al. [26] identified economic factors and lack of knowledge as the main barriers for solar thermal market penetration after conducting a series of interviews among forty planners, contractors, manufacturers and customers, mostly from Germany. Similarly, Munari-Probst, Roecker [27] used a multiple choice web survey, addressed to architects, engineers and façade manufacturers in order to identify patterns for the aesthetical evaluation of solar thermal components for integration. It was found that general architectural rules do apply when integrating solar collectors into buildings, favouring customisation and variety of shapes and colours to ease acceptability.

This paper contributes to the general knowledge in the field, presenting the results from an exploratory survey and discussing the findings considering previous research. The survey addressed several development stages separately in order to distinguish particular issues to overcome during design, production and assembly of building services integrated façades. Furthermore, the findings were categorised and discussed in terms of process and product related barriers, generating an information matrix with specific issues to solve for each category and development stage, considering their perceived importance based on a qualitative and quantitative assessment of the gathered responses.

2. Strategy and methods

The assessment was based on data gathered through an exploratory survey addressed to professionals involved in any stage of the façade development process. Hence, architects, façade consultants, façade engineers and suppliers were considered as the target group. The survey sought to bring new knowledge in the field of façade design and construction, discussing barriers for the specific implementation of building service integrated facades, being understood as a particular façade product.

The assessment and discussion centred around the identification of the main perceived problems in distinct façade development stages, so the questionnaire consisted mostly of open-ended questions. The respondents were asked to state up to three main problems, in order of relevance, that they perceive as key issues during design, production and assembly stages, separately. Later, all gathered responses were examined using conventional content analysis techniques. Content analysis is a widely used tool for qualitative analysis, to interpret meaning from the content of text data. The conventional approach is used when coding categories are obtained directly from the observation of the data [28,29]. Thus, main perceived problems were categorised in relevant nodes or general topics, for the discussion and prioritisation of main barriers to overcome. The chosen approach allowed for the use of mixed evaluation methods, to address different aspects of the assessment.

On the one hand, a quantitative evaluation was conducted through descriptive statistical analysis, exploring the information in terms of the frequency of each identified node for the definition of the main barriers. Hence, it was possible to discuss and compare the perceived relevance of the different key topics within each development stage, establishing priorities. On the other hand, qualitative evaluation was the basis of the assessment, considering the exact responses for the discussion of detailed problems to state recommendations for further development. The exact non-formatted responses were used for an early assessment and are presented in the form of frequency based word maps in the result and discussion section of this document, for each defined stage. The word maps were made using the exact words from the responses, and considered all words mentioned at least two times, after filtering connectors and other auxiliary words without standalone meaning. Word frequency count and the use of word clouds as graphical representations are commonly used as valid tools in content analysis of exploratory surveys or interviews, assisting in the identification of relevant trends, concepts or topics [30].

2.1. Questionnaire and survey

The questionnaire was structured in three main sections: (I) Basic Information, (II) Design process of building services integrated facades, and (III) Integration of solar technologies in the building façade (Appendix A). The first section dealt with basic information to assess the background and experience of the respondents. The second section focused on the development of building services integrated facades, seeking to identify the main problems encountered during design, production and assembly stages. Finally, the third section sought to assess the potential for integration of solar technologies in façade systems, identifying specific barriers to overcome for those particular technologies. The results presented in this paper cover the first and second sections of the questionnaire, while the results from the third section (barriers for façade integration of solar technologies) were discussed on a separate paper [31].

The survey was conducted from mid-September to mid-November 2015 and was distributed both as an online form and in printed format among several professional and research networks related to façade design and construction. It is unclear how many people were reached, however, the number is estimated to be between 250 and 300. At the end of the campaign, 133 questionnaires were received, comprising a final number of 79 valid questionnaires after filtering empty (40) and half empty forms (14). The response rate of the survey was 59,4% considering only the received questionnaires, and around 25–30% taking into account the estimated total universe reached. These results fall in line with similar research experiences that have used surveys in the construction field, with response rates ranging from 25,3% to 32% [32,33]. It is relevant to point out that the analysis does not pretend to be exhaustive nor completely representative of façade design and construction issues, but it is regarded as valuable referential information to understand perceived barriers and problems encountered during the development process of building services integrated façades. The assessment of perceived issues from façade professionals is considered relevant due to the role that they play in the decision-making process particularly at early design stages, having an impact on early integration of particular technologies or building services into façade concepts.

2.2. The sample

The first section of the questionnaire aimed to characterise the sample, in order to provide context for the responses that followed. The characteristics of the respondents were defined in terms of background, role in the design/construction process, years of experience, location of projects, and experience with building services integration in facades.

In terms of the background of the respondents (n = 79), the large

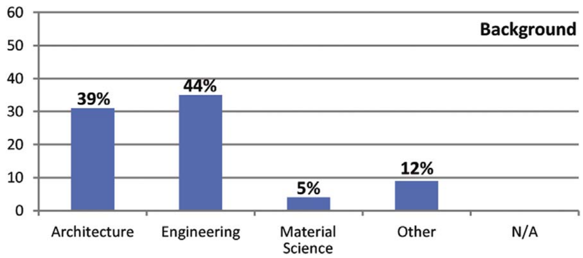

Fig. 2. Sample characterisation according to the background of the respondents.

majority corresponded to engineers (44%) and architects (39%). Only 5% declared that they have a background in material sciences while 12% stated that their background correspond to other disciplines, such as physics, management, or others not specified (Fig. 2).

Regarding the role of the respondents (n = 79) within façade design and construction processes, 53% declared that they mostly have a design related role, either as architects or façade consultants, while 8% of the sample worked as system suppliers and 9% as façade builders. The remaining 30% stated that their roles were not covered by those three alternatives, filing themselves under other roles such as researchers, managers, or consultants in specific issues like energy performance, materials or structural analysis (Fig. 3).

In terms of experience in the field (n = 79), 67% of the respondents stated that they have between 5 and 20 years of experience in façade design or/and construction, and 18% claimed to have more than 20 years. Only 15% of the professionals approached for the survey had less than 5 years of experience (Fig. 4). Furthermore, 66% of the total respondents declared to have specific experience dealing with integration of building services into façade systems. The type of experience referred was not further detailed (Fig. 5).

The respondents were also asked to declare up to three main countries for the location of the projects they have been involved with. The locations are shown in Fig. 6. All mentioned countries are included on the map, with different name sizes according to the amount of mentions. This map is relevant for the description of the sample because it accounts for externalities related to the professional and cultural background of the respondents, so the results also have to be studied taking this information into consideration. As it is clearly shown, the vast majority of the respondents have worked in Europe, particularly in Germany, The Netherlands and UK. There is also a relevant amount of experiences in USA and the middle east (especially UAE) and some scattered responses from the western coast of Africa, Asia and South America. This of course responds to the fact that the survey was distributed along professional networks mostly based in Central Europe, so the results must be judged accordingly.

3. Results and discussion

3.1. Early assessment and categorisation of the responses into general topics

The results discussed in this paper aimed to identify relevant

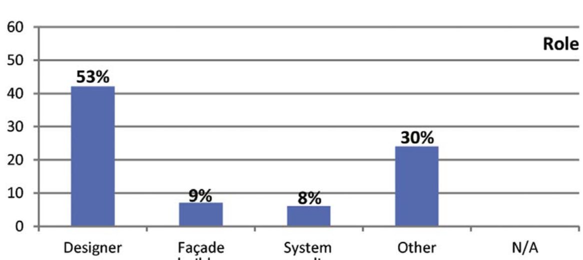

Fig. 3. Sample characterisation according to the role of the respondents in the façade development process.

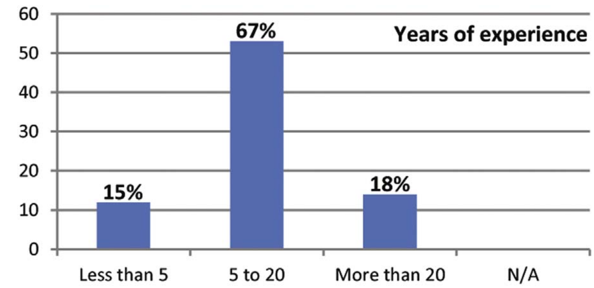

Fig. 4. Sample characterisation according to years of experience.

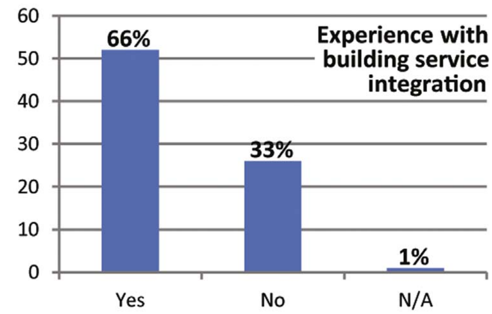

Fig. 5. Experience with building services integration in facades.

problems associated with the integration of building services in façades from the perspective of experienced professionals, considering three main stages: design, production, and assembly. Detailed steps for the understanding of these stages are described in Fig. 7, based on a scheme previously developed by Klein [22]. The questions were open ended, to allow for an exploratory entry to the subject; therefore, the responses were processed and categorised under topics for the evaluation, using content analysis techniques. This step was necessary in order to overcome false conclusions created by different phrasing or word choice by the respondents. However, detailed information from the original answers was preserved and used when discussing the results, to add depth to the analysis. Table 1 shows the complete list of topics recognised during the initial review, organised under two main groups to distinguish and discuss perceived problems related to either the process or the product itself.

Several topics or nodes were identified as process related barriers. Some topics, such as coordination between trades, technical knowledge of professionals, logistics and responsibilities, mostly depend on the professionals involved in the design and construction, or are directly related to internal management of the process. Meanwhile, topics such as the existence of regulation and standards, or public acceptance are regarded as externalities that may affect the process at different stages, compromising the final result.

Regarding the product itself identified topics considered technical feasibility, physical integration, durability, performance, aesthetics and availability of the required components and systems to be integrated. It is relevant to point out that these categories were devised for this particular analysis, based on the responses gathered through the survey, so they are not presented as definitive categories for a general understanding of the matter at hand. Furthermore, this categorisation does not change the original information in any aspect, allowing for alternative points of view to conduct further analyses of the basic unformatted dataset.

Fig. 8 shows the number of total mentions for each particular topic, considering all three development stages within the process (design, production and assembly). Two points are worth mentioning: First of all, some topics, although mentioned in the responses, do not seem to be perceived as relevant as other groups. This is clearly noticeable in the cases of ‘acceptance’, ‘regulation’, ‘environmental impact’, and

Fig. 6. Main location of projects from the respondents. Word sizes illustrate the amount of mentions.

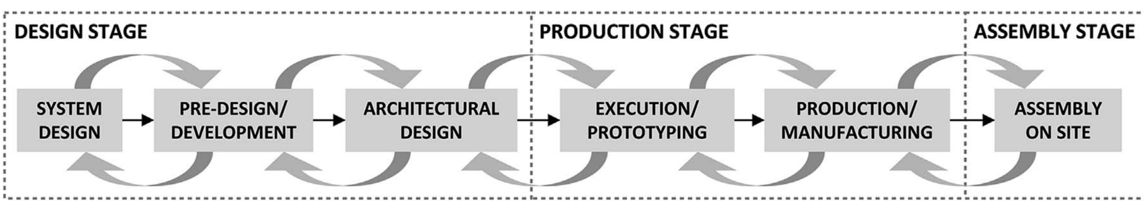

Fig. 7. Stages of development process for façade products (based on scheme in Klein [22]).

Table 1
List of identified topics for the categorisation of the responses.

GROUPS	TOPICS
PROCESS	Coordination Knowledge Logistics Time Cost Responsibilities Acceptance Regulation Environmental impact
PRODUCT	Technical feasibility Physical integration Durability & maintenance Performance Aesthetics Availability

'availability'. For this reason, it was decided to combine the process related topics into an 'others' category for further evaluation and discussion of the results. Secondly, there seem to be topics with high perceived relevance on all three stages, such as coordination between professionals, or physical integration of the required components in the façade module; while some others are particularly relevant in a specific stage, such as aesthetical and performance concerns during the design stage.

This initial assessment presented an overview of the formatted responses, establishing general trends for the defined categories in each development stage. Nonetheless, each category has different connotations and impacts on each stage, resulting on specific problems to be addressed. Consequentially, a detailed analysis of the responses from the questionnaire was performed, evaluating each stage separately to address particularities mentioned by the respondents. Furthermore, the mention order stated in the responses was taken into account to discuss perceived priorities within each defined category.

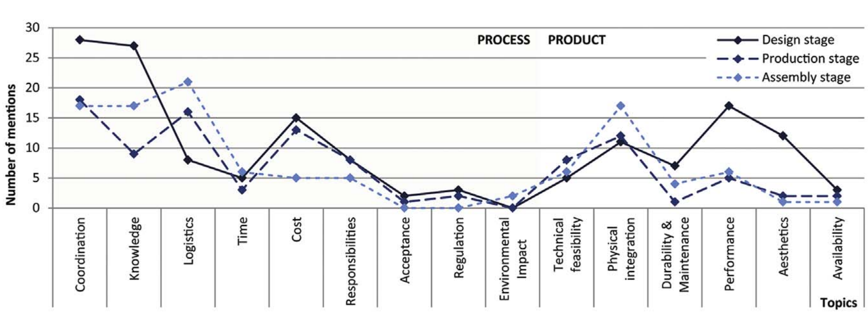

Fig. 8. Number of mentions per each identified topic.

Fig. 9. Word map of main perceived problems during design stage.

3.2. Main identified problems during the DESIGN STAGE (n = 151)

Fig. 9 shows a word map composed with all the responses from the respondents when asked about the main perceived problems during the design stage. Complementary, Fig. 10 shows all formatted responses categorised according to the topics mentioned above. The respondents were asked to mention up to three main problems related with each stage, in order of relevance. Therefore, the analysis considered this when assessing the results, as shown in the graph.

By looking at the word map, it is clearly noticeable that there are topics that particularly stand out, illustrated by the use of words such as cost, knowledge, design and performance. The presence of these words does not seem surprising, given that these are indeed common relevant topics within the field of façade design and overall building technologies. However, the graph shows differences on the perceived relevance of the problems, after reviewing and formatting the responses. For instance, 'cost' is indeed mentioned extensively, but it represents the fourth most relevant group of problems considering the total of mentions, while it drops to the sixth place, along with 'aesthetics' and 'logistics' if we consider just the 1st mentioned problem. This means that even though 'cost' is without a doubt a relevant issue during the design stage, was not perceived as relevant as others such as 'knowledge' or 'coordination' among the respondents.

In terms of total number of mentions, problems about 'coordination' and 'knowledge' seem to be perceived as the most relevant within the design process, followed by 'performance', 'cost', 'aesthetics' and 'physical integration'. The specific problems identified by the respondents are discussed below, according to each one of the main topics.

Among problems regarding coordination issues, the most cited ones addressed difficulties on the communication between professionals from different areas. Specifically there seems to be a widespread lack of coordination between designers/façade consultants and building services specialists, which may result in redundancies, and overall inefficiency within the design process. Furthermore, the respondents declared that there is no integral vision ruling the development process, but all professionals are concentrated on solving specific sectorial problems instead. This adds to the fact that common targets are not usually defined, which may lead to deviations from core issues.

In terms of knowledge, the main complaint was the widespread lack of knowledge of designers and façade consultants. Moreover, this situation becomes more relevant considering a perceived lack of technical experience from suppliers and the communication issues discussed above. Besides the direct impact of the lack of technical knowledge on the design of building services integrated façade systems, there are indirect impacts declared by the respondents that influence the decision to develop these systems, such as the presence of prejudices or misguided expectations based on unrealistic aims.

Problems about performance fall under two types. Foremost, the main number of mentions follows problems related with the lack of tools for the accurate prediction of long term performance during early design stages. Several respondents declared that there is need for more empirical information to validate theoretical or numerical simulations for the assessment of integrated technologies, considering diverse climates and particularities from regional contexts. Secondly, some problems were identified concerning technical limitations of current systems, in terms of their achieved performance. This is perceived as particularly relevant at comparing the energy performance of compact units against the energy performance of centralised systems that cannot be fully integrated in the building façade. Besides the necessary optimisation of current systems in terms of their own performance, some identified problems discussed the expected performance of the entire façade component, considering an extra technical complexity to properly fulfil functions such as secure air tightness or provide thermal resistance. In this aspect, the performance assessment of an integrated façade component should consider the multi functionality character of the building enclosure.

Regarding cost issues, the evident problem was the perception that integrated facades would cost more, along with the difficulty for the designer to undoubtedly prove that these higher costs would in turn generate a return of the investment on the long term. Nonetheless, some respondents declared that even if it increases the cost, the main issue is about the budget structure of the development process which is segmented on different trades, making an integrated approach difficult to assimilate under current budgetary conditions.

Aesthetical aspects were not particularly explained among the responses, besides the main concern that the aesthetical quality of the façade concept should have more relevance during the discussion in early design stages. Nonetheless, some respondents declared some detailed problems related to aesthetical concerns, such as the lack of variety in terms of design solutions and available building systems, and the size of the components that need to be integrated.

Lastly, regarding problems categorised under 'physical integration', three main issues were identified: one general aspect and two specific issues to solve. The first one was the added complexity by having to integrate building physics aspects and building services into existing construction principles, requiring a clear identification of the structural system of the façade component. The specific issues identified by the respondents were related to the available space for service integration in façades, and the compatibility of the integrated technologies in terms of connections to be solved. The main concern expressed regarding the lack of space was referred to the depth of curtain-wall facades, which

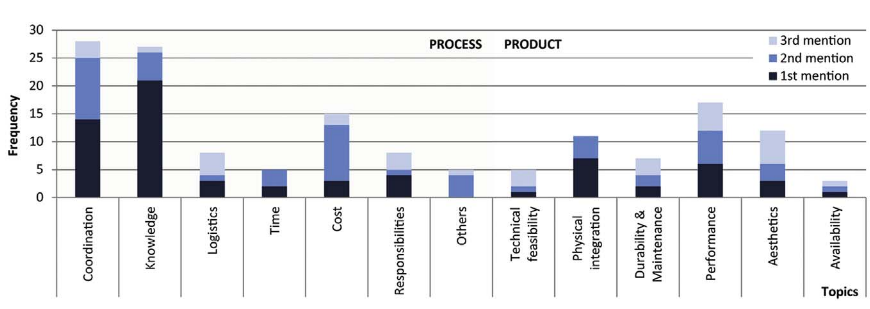

Fig. 10. Main problems during design stage categorised on identified topics.

Fig. 11. Word map of main perceived problems during production stage.

presents a major limitation for integration of conventional building systems.

3.3. Main identified problems during the PRODUCTION STAGE (n = 101)

Fig. 11 shows the word map for the identified problems during the production stage, which includes prototyping and manufacturing of the required components. As expected, the use of words mostly respond to technical issues from the manufacturing and construction process, as seen by the prominent use of words such as 'production', 'cost', 'feasibility', 'components', 'materials' and 'technical' itself.

By looking at the total amount of categorised mentions shown in Fig. 12, 'coordination' related problems again are perceived as the most relevant, followed by 'logistics', and then on a third level, 'cost' and 'physical integration'. This trend slightly changes by solely focusing on the first mentioned problem, showing a rise of 'cost' and 'physical integration' over 'logistics'. Even though logistics related issues remain relevant, it seems that 'cost' and 'physical integration' are perceived as a more pressing source of problems during the production stage. At the same time, although mentioned, the frequency of knowledge related problems is particularly low, especially considering only first mentions. This seems to point out that while more knowledge is clearly needed during design stages, it does not seem to be a major concern during production, hinting at a mature and trained industry.

Regarding particular problems associated with the mentioned categories, most problems grouped under 'coordination', are related to the lack of communication between professionals from different areas. Following problems encountered under the design stage, there seem to be lingering concerns about the lack of proper communication channels between designers and manufacturers during production stages. In turn, this may result in mismatches between design and built concept, and hinder the possibility to allow feedback to/from the design team. A second relevant aspect regarding communication among professionals is the perceived difficulty associated with the coordination of sub-contractors and sub-suppliers. This holds true both in terms of extra time and associated costs of a disaggregated process and in terms of the distribution of responsibilities among the professionals for achieving the expected goals.

The main problem regarding cost was again the increased costs associated with integration of building services. Furthermore, it was mentioned by some respondents that the required 'high quality' of the building solutions would imply higher costs when compared with conventional façade components. Other relevant issue identified by the respondents was the occasional mismatch between initial costs predicted during design stages and the real cost of the production process. This uncertainty of course increases perceived risks and generates prejudices associated with services integration in façades.

In terms of physical integration, the mentioned problems refer to the compatibility between the different systems to be integrated and the constructive components of the façade, and between the service systems themselves. From the responses, these compatibility problems mostly comprehend two aspects: the size and modulation of the components, which do not follow standardised dimensions that could facilitate their integration; and the definition of their interfaces, both in terms of the actual connexions to be solved and the different materials that have to be accounted for. Furthermore, these issues add more complexity to the design of the systems, multiplying the necessary number and types of components to fulfil the required functions, which relates to the technical feasibility of the overall façade concept.

Problems related to the logistics of the process mainly refer to the lack of flexibility within the production and supply chain. The respondents declared that specially the façade assembly line is not typically equipped to integrate services during production, which hinders the use of prefabrication as a widespread method for production. Several respondents agreed to the fact that there is a need for new working models to assist the development of new integrated façade concepts.

Regarding problems about the required knowledge to fulfil the goals, the responses focused mostly on the lack of qualified technical staff overseeing the production process, combined with a lack of skilled workers on site, with experience handling these integrated façade components. Several respondents claimed the importance of having professionals with particular experience in integration, within façade building companies, in order to facilitate communication channels to service suppliers, and to properly advice designers in technical issues related with the production process. Nevertheless, as stated before, these issues were not perceived as relevant as others previously discussed.

3.4. Main identified problems during the ASSEMBLY STAGE (n = 109)

Fig. 13 shows the word map for the identified problems during the assembly stage, which considers the activities destined to connect all façade components between themselves and the rest of the building. The fact that the main activities deal with the coordinated assembly of several components on site is clearly expressed by the choice of words by the respondents. Among the most used words are 'site', 'assembly', 'coordination', 'construction' and 'different', followed by words directly related with integration, such as 'technical', 'services', 'building', 'systems', 'façade' and 'time'.

In terms of the number of mentions by topic, the graph in Fig. 14

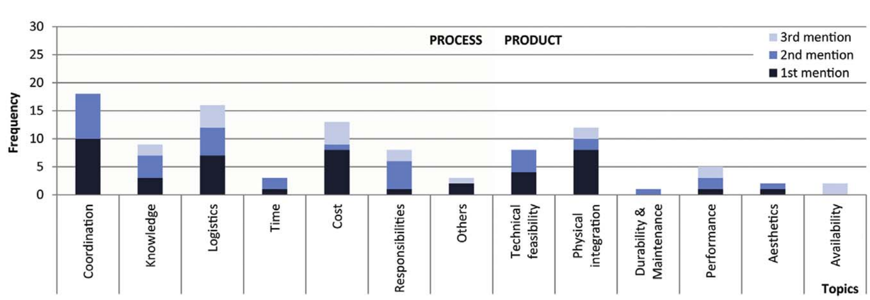

Fig. 12. Main problems during production stage categorised on identified topics.

Fig. 13. Word map of main perceived problems during assembly stage.

shows an even distribution among the different categories, with the exception of four topics that remarkably stand out ('coordination', 'knowledge', 'logistics' and 'physical integration'). Regarding both total amount of mentions and 1st mentions, process related problems seem to be the most relevant ones, particularly considering 'coordination', 'knowledge' and 'logistics'. Constructive problems related to the physical integration of the components and systems were identified as the most relevant product related aspects to overcome.

Besides communication problems among different specialists previously discussed on other stages, coordination problems during the assembly stage seem to be closely linked to the logistics to conduct the required activities on site. The assembly process appears to be seen by the respondents as a coordination exercise between different trades to build the final product. Furthermore, this fact is supported by the limited use of prefabricated unitised modules, leaving the physical integration and connection of the services to be conducted on site. Besides these aspects, other logistics issues mentioned were the transportation and handling of units and components on site, and unexpected issues related to particularities from the context.

As expected, problems regarding lack of knowledge, referred to the lack of training and competence of the workforce on site. This issue represents the large majority of responses related with this topic, with some respondents detailing the necessity to count with installers with multifunctional skills and experience to supervise the assembly process. Some respondents declared that façade contractors in charge of assembly tasks, do not usually know about technical aspects of building services, while others declared that the over specialisation of building services installers means that their knowledge is too focused, disregarding technical aspects of building envelope construction, which may cause risks for the overall quality of the building, as mentioned in the survey.

In terms of physical integration, most mentioned problems were related to the interfaces between the services to be integrated and other components. Several respondents advocated for the need to account for tolerances between the different components to allow for easy integration on site. Some cases were mentioned where products did not fit or where façade units became heavier than expected, due to a miscalculation during the design stage or due to a change on the specifications on later stages which was not considered until the assembly stage. Furthermore, it was stated that the connections should be designed considering the number of components, different materials and easiness of construction. An overly complex assembly method may be a source of countless problems, so, a low number of steps, based on a 'plug & play' assembly concept was recommended.

Overall, it was mentioned that the reality on site may differ greatly from the theoretical parameters considered during the design stage, which would imply extra work and time during the assembly stage to account for unforeseen variables. Some respondents addressed this issue by supporting more use of prefabricated integrated façade components, assembled off site under rigorous technical supervision.

3.5. Summary of the main identified problems and recommendations

A summary of the main identified problems is shown below. Table 2 comprehends problems related with the process while Table 3 shows problems related with the product itself. The categories shown are the most mentioned categories overall. Furthermore, the relative relevance of each set of problems is addressed in the tables, using a scale of colours based on the total amount of mentions of each category per stage. Hence, darker categories are perceived as more pressing to overcome than lighter ones, within each stage.

By looking at Table 2, it is clear that problems related to coordination are perceived as the most relevant ones, which is a fact that holds true in all three defined stages. Hence, it seems highly important to promote clear communication channels between all professionals involved in the process. Secondly, there is a perceived lack of technical knowledge and expertise dealing with integrated building services, particularly during design and assembly stages. Trained designers would be able to incorporate technical input at early design stages, easing communication with façade engineers while minimising mismatches between design and production stages. Moreover, a skilled and trained workforce on site would decrease construction times and the occurrence of errors during assembly.

The fact that lack of knowledge does not appear to be as relevant during production stages, seems to be a sign that façade building companies have enough experience and maturity to undertake the required activities without relevant problems. However, it was pointed out that there are several logistical issues that need to be addressed to allow for façade integration. In general, a main concern stated was the lack of flexibility within the production chain, hindering innovation. In this aspect, the development of alternative production processes, with emphasis on off-site production, and the generation of new business models for the development and management of high-performance facades, are regarded as promising ways to promote widespread façade integration of building services, promoting collaboration while reducing associated costs of current standalone enterprises [34,35].

In general terms, the findings fall in line with the results from other research experiences previously discussed in the document, which state the relevance of process related barriers. Both Klein [22] and Ledbetter [24] advocated for the need for better coordination within the process,

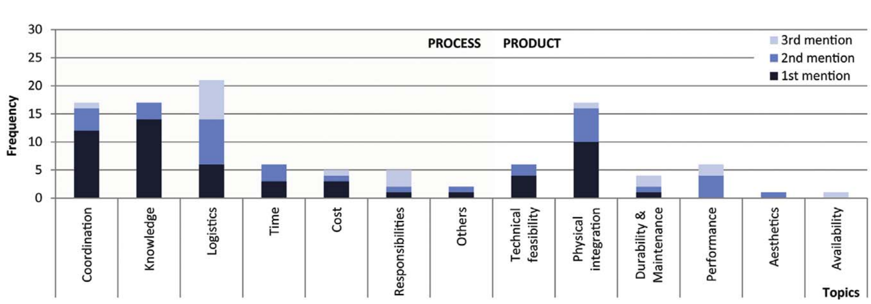

Fig. 14. Main problems during assembly stage categorised on identified topics.

Table 2
Main identified problems per development stage and category (process related problems). Darker colours represent higher amount of mentions per stage.

	PROCESS RELATED PROBLEMS				
	COORDINATION	KNOWLEDGE	LOGISTICS	COST	RESPONSIBILITIES
DESIGN STAGE	- Communication difficulties between professionals from different areas. - Lack of coordination between designers/façade consultants and building services specialists - No integral vision ruling the development process. Common targets are not usually defined	- Lack of knowledge of designers and façade consultants. - Lack of technical experience from supplier - Prejudice and misguided expectations based on unrealistic aims.	- Additional planning effort - Building services are addressed too late in the design and decision making process.	- Higher perceived cost of integrated facades - Difficulty for the designer to prove return of investments on the long term. - Budget structure of the development process, segmented on different trades.	- Responsibilities are not defined.
PRODUCTION STAGE	- Lack of communication between professionals from different areas. - Lack of communication channels and feedback between designers and manufacturers during production stages. - Difficult coordination of subcontractors and sub-suppliers.	- Lack of qualified technical staff overseeing the production process. - Lack of skilled workers on site with experience handling integrated façade components. - Need for professionals with particular experience in integration working in façade building companies.	- Lack of flexibility within the production and supply chain. - Façade assembly line is not typically equipped to integrate services during production. - Need for strong quality control and mid-production testing.	- Higher costs associated with the high quality of solutions required for the integration of building services. - Mismatch between predicted costs during design stages and the real costs of production.	- Responsibilities are not clearly defined. - Refrain of responsibility from façade contractors due to fear of risk.
ASSEMBLY STAGE	- Lack of communication between professionals from different areas. - Number of different trades and suppliers involved in assembly.	- Lack of training and competence of the workforce on site. - Need for installers with multifunctional skills and experience to supervise the assembly process.	- Transportation and handling of units and components on site. - Divergencies between designed assembly method and its application on site. - Context related issues. - Limited use of prefabrication implies more activities to be conducted and coordinated on site.	- Higher assembly costs - Projected costs do not usually match real assembly costs due to particularities from site.	- Unclear responsibilities and warranties.

promoting feedback among the stakeholders from early design stages, while lack of knowledge was referred to by Zelenay et al. [25], Ledbetter [24] and Cappel et al. [26]. Cost is a relevant issue to overcome according to Haase et al. [23] and Zelenay et al. [25]; however, besides particular aspects to solve during production, it does not seem to be a pressing matter for the surveyed experts. This may be evidence of confidence on further technical development and advances that may decrease associated costs, while exploiting reported benefits related to comfort and efficient energy usage.

In terms of product related problems, physical integration seems to be the most relevant issue during both production and assembly stages (Table 3). Additionally, the lack of tools for the prediction of long term performance, and operational limitations of current available systems were stated as problems during design stages.

Discussing integration issues, low compatibility between different systems was the main source of concerns, considering contrasting dimensions and multiple connections to solve among different materials and components, under no unified standard. Hence, recommendations for future product development revolve around the need for components especially designed for integration from early stages, solving connection and compatibility issues through standardisation and modularity. Furthermore, some respondents advocated for the use of modular and prefabricated components, under a 'plug & play' integration approach, to minimise problems during the assembly stage by simplifying complex connections on site; an statement shared by authors such as Mach et al. [36].

In this sense, modularity has to be understood not only as the partitioning of a larger system, but as an holistic approach to the design of the components, defining their architecture and their interfaces to ensure the correct operation of each module and the whole systems. Moreover, the façade construction industry should aim to apply modularity not only in use and production, but also and particularly in design. Modular use allows for customisation through standard dimensions, while modularity is a key aspect for the mass production of components to be assembled later on. However, according to Baldwin and Clark [37], a system is modular-in-design if the process itself can be split up and distributed across separate modules, coordinated by design rules instead of consultation amongst designers. This approach could potentially promote innovation, generating a new framework for a more cost-effective development of integrated facades.

At the same time, aesthetical aspects should be considered, providing an array of products in terms of shape, colours and sizes to allow for customisation [38]. Furthermore, the performance of components and systems needs to be improved, considering not only their operation but also the durability of their individual parts, which has an impact on long term maintenance activities.

Several other technical aspects that need to be further enhanced were stated by the respondents, being regarded as relevant information for product development. Nevertheless it is important to reiterate that process related barriers in general, and coordination between

Table 3
Main identified problems per development stage and category (product related problems). Darker colours represent higher amount of mentions per stage.

	PRODUCT RELATED PROBLEMS				
	TECHNICAL FEASIBILITY	PHYSICAL INTEGRATION	DURABILITY & MAINTENANCE	PERFORMANCE	AESTHETICS
DESIGN STAGE	- Overall feasibility of the intended design. - Size of components that Need to be integrated.	- Added complexity of integrating building physics, building services and façade construction principles. - Available space for service integration in facades. - Compatibility of systems and connections to be solved.	- Maintenance provision and durability of the components over time. - Consider access for maintenance in the design. - Distributed systems are more complicated to maintain (cost and effort).	- Lack of tools for the accurate predction of long term performance. - Technical limitations of current systems in terms of their achieved performance. - Multifunctional performance of the façade component is not usually considered.	- Aesthetical quality of the façade concept shoud have more relevance during discussions on early design stages. - Lack of variety in terms of design solutions and available building systems
PRODUCTION STAGE	- Overall feasibility of the intended design. - Appropriate level of complexity.	- Compatibility between systems to be integrated and façade components. - Lack of standardised dimensions and modular components for an easy integration. - Multiple connections to solve and different materials to consider.	- Maintenance issues.	- Achieving expected performance in terms of the systems and façade functions.	- Meet aesthetical requirements from architects.
ASSEMBLY STAGE	- Feasibility of the assembly on site. - Unnacounted size/weight issues of the services to be integrated.	- Need to account for tolerances between components. - Connection of several number of components and different materials. - Lack of modularity and/or standardised dimensions and conections.	- Maintenance issues - Limited possibilities to conduct repairments.	- Testing of operation of systems and components. - Limited communication of operation modes and user control parameters to users.	- Low attention to aesthetical quality of joints and details.

stakeholders and lack of knowledge in particular, are perceived as the most crucial barriers to overcome. Hence, while it is important to further develop an array of products for façade integration, the most pressing efforts should be focused on devising new multidisciplinary façade design and production processes, and on including integration issues in designers' education, in order to promote the development and widespread application of building services integrated facades.

4. Conclusions

This paper aimed to discuss barriers for the integration of building services in façades, by identifying relevant problems and issues during design, production and assembly stages. The method chosen for the study was an exploratory survey addressed to professionals with practical experience in the development of façade systems for office buildings.

General results showed that barriers related to the process itself are perceived as more pressing to solve than issues about the end product, to promote façade integration of building services. Furthermore, specific issues were identified in all three defined development stages: main problems during design stages were particularly characterised by coordination and lack of knowledge. Main problems during the production stage were mostly perceived in relation to coordination, logistics, cost and physical integration, while lastly, main perceived problems during assembly stages dealt with coordination, lack of knowledge, logistics and physical integration of systems and components.

As particular recommendations, it seems highly important to promote clear communication channels between all professionals involved in the process, and encourage the development of alternative production processes, with emphasis on off-site production, and the generation of new business models for façade development, in order to incorporate more flexibility into the supply and production chain. In a similar note, product development efforts should aim to generate a wide array of components under a modular design approach, considering connection and compatibility issues related to their physical integration.

Finally, it is important to point out that given the scope and scale of the study, the analysis did not pretend to be exhaustive. Even though the findings represent relevant referential information for the development of integrated façades, more studies are needed to comprehensively assess barriers and possibilities for widespread façade integration of building services. The definition of local variables to assess potential for application on different contexts and the validation of the findings through case studies or in-depth interviews are regarded as possible research paths for the short-term future.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jobe.2017.07.008.

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