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Solar façades

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DOI
10.7480/jfde.2017.1.1398

Publication date
2017

Document Version
Final published version

Published in
Journal of Facade Design and Engineering

Citation (APA)
Prieto Hoces, A., Knaack, U., Auer, T., & Klein, T. (2017). Solar façades: Main barriers for widespread façade integration of solar technologies. *Journal of Facade Design and Engineering*, *5*(1), 5. https://doi.org/10.7480/jfde.2017.1.1398

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Solar façades – Main barriers for widespread façade integration of solar technologies

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Abstract

Solar energy has been actively promoted as a clean energy source since 1973's oil crisis, evidenced by the emergence of initiatives such as the Solar Heating & Cooling Programme of the International Energy Agency or the US Department of Energy. Nonetheless, solar technologies have not been widely used in the built environment, limiting their operation to industrial and macroscale applications. Commercially available products such as building integrated PV panels (BIPV) or building integrated solar thermal collectors (BIST); and novel prototypes and concepts for solar cooling integrated facades are seen as interesting alternatives for the development of new performance based façade components for high-performing commercial buildings. However, there are barriers to overcome in order to promote widespread application of architecturally integrated solar components.

The present paper seeks to discuss perceived barriers for widespread façade integration of solar technologies, in order to define the current scenario and generate guidelines for future developments. In order to achieve this, the paper presents the results of a 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, architects, façade consultants, system suppliers and façade builders were considered. The outcome of this study is the definition of the main perceived barriers for façade integration of solar technologies, discussing the results from the survey along with other related experiences found in the literature.

This study is part of the ongoing PhD research project titled COOLFACADE: Architectural integration of solar cooling strategies into the curtain-wall, developed within the Façade Research Group (FRG) in the Green Building Innovation programme (GBI) of the Faculty of Architecture and the Built Environment, TU Delft.

Keywords

Solar technologies, PV, Solar thermal collectors, Solar cooling, Façade integration, Survey

DOI 10.7480/jfde.2017.1.1398

1 INTRODUCTION

Worldwide energy consumption is expected to greatly increase during the next three decades. Predictions elaborated by the US Energy Information Administration (EIA) show that by 2040, world energy consumption will present an increase of 48%, compared to consumption levels registered in 2012 (DOE/EIA, 2016). Similarly, in the last annual energy outlook released by BP, it was declared that an increase of 35% in total energy usage is expected between 2014 and 2035 (BP, 2016). This panorama clashes with IEA reports which state that energy production and use presently account for two thirds of worldwide greenhouse gas emissions, supporting the need to lower them, while sustaining the growth of the world economy (OECD/IEA, 2015). As a matter of fact, it has been stated that the expected consumption increase will be mostly supported by non-OECD nations, in order to drive long term economic growth, so even if energy saving campaigns and strategies are enforced worldwide, there will still be a demand for alternative sources of energy.

Solar energy has been actively promoted as a clean energy source since 1973's oil crisis, evidenced by the emergence of initiatives such as the Solar Heating & Cooling Programme of the International Energy Agency (IEA-SHC, 2016) or the US Department of Energy (DOE, 2016). Nonetheless, besides scattered examples, the introduction of solar technologies into the built environment has not been massively accepted, which seems relevant considering that the building sector accounts for 40%-45% of the total energy demand (EP, 2002). Important advances have been made in the development of solar driven building products for façade integration, such as semi-transparent PV glazing (Fung & Yang, 2008; Li, Lam, Chan, & Mak, 2009), PV and solar thermal collector integrated shading devices (Frontini, 2011; Mandalaki, Zervas, Tsoutsos, & Vazakas, 2012), or coloured glazed thermal collectors by means of multi-layered films (Schüler et al., 2005) and selective paint coatings (Joly et al., 2013; Orel et al., 2007). However, these have been proven insufficient in order to promote widespread application in buildings.

This paper seeks to contribute to the field, by presenting the results of an open ended survey addressed to professionals with practical experience in the development of façade systems for office buildings. The main goal of the survey was to identify main requirements and barriers for façade integration of building services, as a way to promote the development of new cost-effective multifunctional façade products for high-performance office buildings. The first part of the survey dealt with design and construction problems related to the integration of building services and was discussed on a previous paper (Prieto, Klein, & Knaack, 2016). The second part was specifically aimed to identify the main barriers for façade integration of solar technologies. Hence, this paper presents the perceived barriers and compares the findings along similar research experiences on the topic.

Among related experiences it is possible to count surveys carried out to identify barriers for the application of building integrated photovoltaics (BIPV) and building integrated solar thermal panels (BIST). Yang (2015) discussed technical barriers for façade integration of PV panels, considering design, construction, commissioning and operation stages. Her findings highlighted the need for advanced simulation tools and monitoring platforms to assist the role of designers and building managers. Cappel et al. (2014) stated that economic factors are seen as the most relevant barrier, with an important lack of knowledge from architects as the second most important problem for market penetration of facade integrated solar thermal systems. Also discussing thermal collectors, Munari Probst and Roecker (2007) stated the need for more design flexibility regarding aesthetical aspects such as shape and colour of integrated building components.

One of the most relevant works about barriers for architectural application of solar technologies was made as one of the outcomes of Task 41 of the Solar Heating & Cooling Programme of the International Energy Agency. A web-based multiple choice survey was distributed among architects in 14 participating countries, to assess their use of solar technologies, perceived barriers for implementation, and satisfaction levels of commercially available products. Results from 394 valid questionnaires showed that economic aspects are the main issues to overcome, followed by knowledge and information about solar technologies and product availability (Farkas & Horvat, 2012).

The information presented on this paper is organized according to two main aspects. First, barriers were identified and assessed in terms of perceived relevance by the interviewees, comparing the results to the findings of Farkas and Horvat (2012). Secondly, key aspects among the barriers were discussed, giving particular attention to perceived barriers related to the products themselves, in order to draft recommendations for future product development, based on requirements and experience from experts in the field.

2 METHODOLOGY

2.1 THE SURVEY

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. 133 questionnaires were recovered, consolidating a final number of 79 valid questionnaires after filtering empty (40) and half empty forms (14). The questionnaire was structured explored design and construction issues related to the integration of building services in general while also considered specific questions about the integration of solar technologies. This paper focuses on the second part of the questionnaire.

Multiple choice questions were analysed through descriptive analysis, while open ended questions were processed following content analysis methods. The findings from Task 41 were used as reference for the evaluation of the responses, allowing for comparisons. The analysis does not pretend to be exhaustive nor completely representative, however, it is seen as valuable information to understand perceived barriers and detect key aspects to overcome in order to develop architecturally integrated solar façade components.

2.2 THE SAMPLE

The questionnaire was 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, which meant different backgrounds and experience within the sample. In terms of the background of the interviewees (n=79), the large majority corresponded to engineers (44%) and architects (39%) as shown in fig.1. Regarding experience in the field, 67% of the interviewees stated that they have between 5 and 20 years of experience, 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.2).

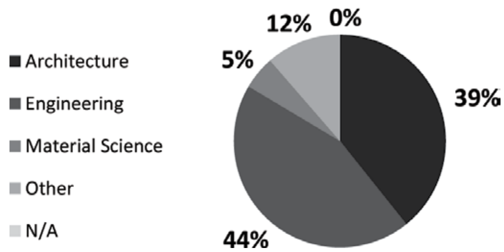

FIG. 1 Declared background of the interviewees

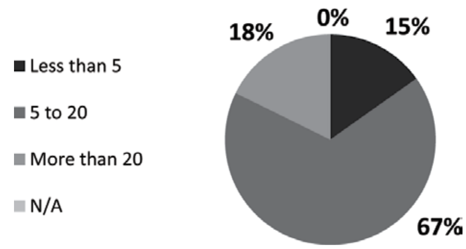

FIG. 2 Declared years of professional experience

Familiarity with solar technologies was evaluated, considering direct experience with PV panels, solar thermal collectors, and solar cooling technologies. The interviewees were allowed to check more than one alternative, in case they had experience with more than one type of technology. Almost half of the sample (47%) declared to have had direct experience with photovoltaic cells, while 38% declared the same for the case of solar thermal collectors. As expected, a smaller group of interviewees declared to have particular experience dealing with solar cooling technologies. Lastly, 33% declared not to have any experience working with solar technologies. This fact is worth mentioning because it means that around two thirds of the sample does have direct experience working with the cited technologies, which validates their appreciations on the topic.

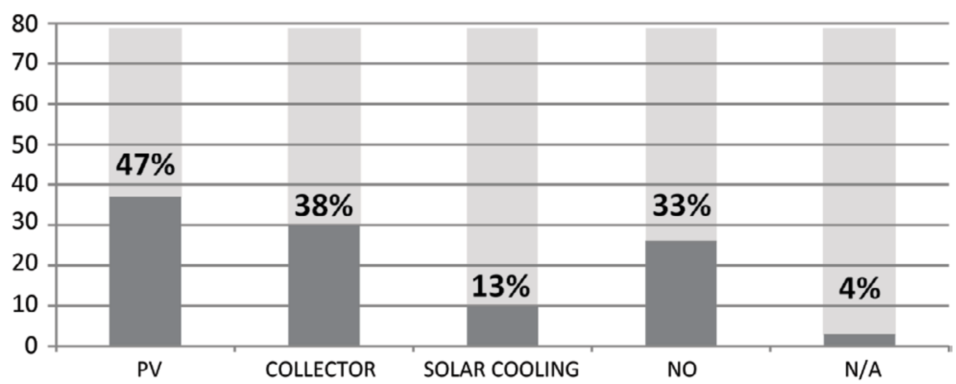

FIG. 3 Declared experience with solar technologies

3 RESULTS AND DISCUSSION

First of all, figures 4 and 5 show the overall perception of the interviewees regarding possibilities for integration of solar technologies in façade systems. Figure 4 illustrates the perceived potential for further development of solar integrated façade products. The vast majority of the interviewees (91%) believed that there is potential for integration, while only 6% were not sure and 3% did not provide an answer. It is worth mentioning that nobody declared to believe that there is no potential for further developing façade products integrating solar technologies. The main reason declared by those who were not sure about façade integration potential was the difficulty associated with the development of cost-effective solutions, due to low efficiency and high costs of current systems.

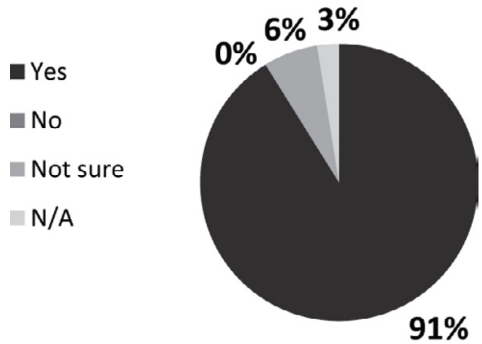

FIG. 4 Perceived potential for solar façade integration

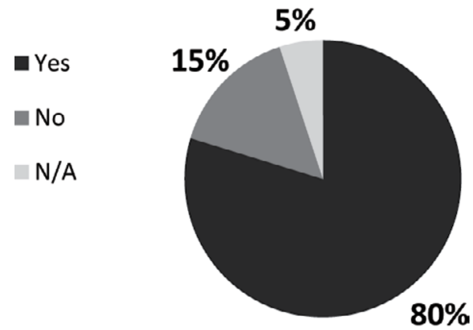

FIG. 5 Current market for solar façade products

Furthermore, the interviewees were asked if they believe that there are current market possibilities for commercial application of solar integrated architectural products. As shown in figure 5, 80% of the sample believes that there is current commercial demand for these products, while 15% believes the contrary. The main reasons given to support the latter were the high costs of the systems compared with the low cost of energy, and budget management within the conventional facade design and production process, based on separate trends and contractors, obstructing the development of integrated products.

3.1 MAIN PERCEIVED BARRIERS TO PROMOTE WIDESPREAD FAÇADE INTEGRATION OF SOLAR TECHNOLOGIES

The interviewees were asked to state the most important barriers to overcome in order to promote widespread integration of solar technologies into the building envelope. This was an open ended question to assess their perceptions on the subject without external conditioning. Furthermore, the interviewees were asked to mention up to three constraints in order of relevance, so the order of the mentions was considered on detailed further analyses as well.

Figure 6 shows a word map of all issues declared by the interviewees, as a first approach to data analysis. The size of the displayed words, represents their frequency within the sample. The word map was made using the exact words from the responses, considering all words mentioned at least two times, after filtering connectors and other auxiliary words without standalone meaning. No distinction was made based on the mention order of the perceived barriers.

By looking at the word map, it is clearly noticeable that 'cost' stands out as the most used word to refer to integration barriers, which does not come as a surprise. Other topics which received a relevant amount of mentions were related to design aspects ('aesthetics', 'design'), performance of the systems ('performance', 'efficiency', 'energy'), the knowledge to design, implement or operate them ('knowledge'), or the need for extra maintenance activities ('maintenance').

FIG. 6 Word map of barriers declared by the experts

As a second step for data analysis, the responses were processed and formatted into new limited categories to allow for further evaluation. This step was necessary in order to overcome false conclusions created by different phrasing or word choice by the interviewees. However, detailed information from the original answers was preserved and used when discussing the results, to add depth to the analysis. It was decided to use the categories defined by the IEA SHC Task 41 research project (Farkas & Horvat, 2012), for the analysis of the sample (table 1). Therefore, using categories already validated in the literature, while giving the opportunity to compare and discuss the results against previous experiences.

MAIN CATEGORIES	DESCRIPTION OF THE BARRIERS
INTEREST	Lack of interest in solar design by architects and clients/developers
ECONOMY	Not economically justifiable and lack of governmental incentives
KNOWLEDGE	Lack of sufficient technical knowledge by architect, by client/developer and by consultant
INFORMATION	Lack of architecturally oriented literature about these technologies and useful data for architects in product datasheets
PRODUCT	Lack of products suitable for quality building integration and complementary building components
PROCESS	Lack of tools that support design and sizing of systems / Technology is considered too late in the design process (insufficient time and resources)

TABLE 1 Barriers and categories identified by IEA SHC Task 41

The categorised responses are shown in figure 7. As expected, economy related issues have the most amount of first mentions, being perceived as the main barrier to overcome. Secondly, issues about the product itself arose as a relevant barrier, followed by knowledge and information related problems. Lastly, problems related with design and construction processes were also mentioned as the main barrier, along with other topics not considered in the previous categories. Lack of interest was not identified as a barrier in the first mention by any of the interviewed experts.

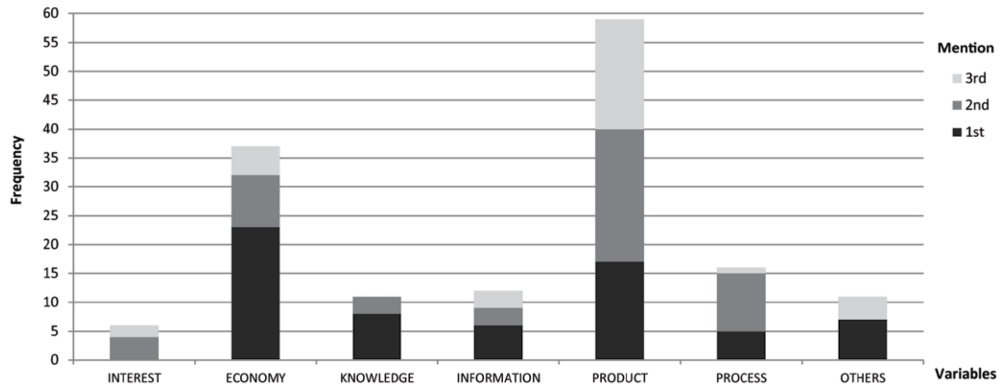

FIG. 7 Main perceived barriers categorised on variables defined by IEA SHC Task 41

Considering the total amount of mentions under each category, ‘economy’, ‘knowledge’ and ‘information’ show a frequency increase without surpassing the number of first mentions. However, in the cases of ‘product’ and ‘process’ related barriers, second and third mentions surpass the first one. This shows that even if these are not strongly perceived as the main barrier to overcome, there are important ‘product’ and ‘process’ related issues to solve in order to promote widespread façade integration of solar technologies. This issue is particularly evident in the need for suitable products for integration. As shown in the graph, it becomes the most pressing issue to overcome considering the total amount of mentions. Of course, different aspects related to the suitability of said products were considered, which will be further detailed in this document.

In general terms, the results obtained from the survey fall in line with the findings from IEA Task 41. Similarly, Farkas and Horvat (2012) declared that economic issues seem to be the main barriers for implementation of solar technologies, although this becomes clearer in the case of the application of PV panels, compared to the use of solar thermal technologies. Discussing possible strategies to overcome the barriers, besides economic measures, the authors declared that even if there have been considerable advancements in the design, look and efficiency of solar components, there is need for new developments and improvements of available products to appeal to architects. The recognition of these two issues by both experiences is seen as a sign of validation for this study, by comparison with a larger sample.

The most relevant differences between both experiences, refer to the perceived lack of knowledge and overall interest to architecturally integrate solar technologies into the building envelope. Task 41 results showed these issues as the second and third most relevant barriers for the use of both PV cells and solar thermal panels. While lack of knowledge was also declared as a relevant barrier during the present study, lack of interest was barely mentioned in comparison with other barriers, and not stated at all as the main barrier (under first mention). On the one hand, this fact could be seen as a sign of increasing interest on renewable energies since the application of the Task 41 survey. On the other hand, another reason to explain this could be the specialisation level of the interviewed experts (professionals from different disciplines with experience in façade design and/or construction) when compared to the surveyed sample from Task 41 (mostly architects). Furthermore, it is relevant to mention that more than 90% of the interviewed experts believed that there is potential for façade integration, whose probably take interest in this technologies for granted. This notion may be supported by looking at the disaggregated results from the Task 41 report, which differentiated between lack of interest by the client and lack of self-interest (by architects). In effect, clients' lack of interest was declared as an important barrier while architects' lack of interest was barely stated as an issue, in a similar way to the present study. Conjectures aside, the fact that ‘lack of interest’ did not appear in relevant numbers as answer to an open ended question, shows that it was clearly not perceived as a defining barrier for the surveyed sample.

Several statistical analyses were conducted to assess potential differences in the perceived barriers between independent groups among the sample, based on background, role, experience with façade integration or solar technologies. Even though some discrepancies were found among the groups, particularly between professionals with and without experience with solar technologies, the deviation was never found significant enough to unequivocally state that perceived barriers change according to different groups. Thus, the discussed results are valid for the different groups allowing for minor variations in judgement. More detailed studies with a larger sample are advised if there is further interest to explore these variations.

3.2 IDENTIFIED ASPECTS TO OVERCOME WITHIN MAIN BARRIERS

Given that the survey was structured in open ended questions, the interviewees had the possibility to freely declare the issues they perceived as the main barriers to overcome for widespread façade integration of solar technologies. This information is regarded as relevant in order to devise focused strategies to cope with the perceived barriers, discussing several mentioned aspects in each category for better understanding. It is worth mentioning that the depth of the discussion is constrained by the level of detail of the gathered responses, allowing for more insight in some topics than others. 'Product' related issues will be presented separately, due both to its relative perceived relevance within the sample and its potential to inform the development of future architectural products. Hence, the discussion will be conducted to the definition of key aspects to overcome for the development of appealing solar integrated façade components.

First of all, issues categorised under 'economy', largely refer to the cost of solar technologies in terms of the economic feasibility and payback time for the initial investment. An additional concern was the current energy price, which is not high enough to promote the emergence of competitive solar driven alternatives on a larger scale. Nevertheless, the energy cost is expected to rise in the future, while at the same time further developments and governmental incentives should encourage the offer of new solar based architectural products for façade integration.

Regarding knowledge, the main concern was the lack of experience and overall knowledge of architects about technical issues and solar technologies in general, obstructing its widespread application. Besides this, there were also mentions of the role of end users, referring to their lack of knowledge on how to operate these systems. Finally, some concerns were also expressed about the experience of the workforce on site, required to successfully assemble the components minimising the occurrence of errors. The perceived lack of knowledge is closely linked with the need for useful information about solar technologies. The interviewees declared that information should be focused on showing purposes and associated benefits to end users, while it also should be clear and complete enough to assist architects during design stages. In this regard, there were concerns about proper documentation of some properties, such as efficiency over time and reliable performance data; and also the need for updated standards for building integration, considering reputable references and state-of-the-art available technologies in the market.

The main issues categorised under 'process' revolved around the perceived need to rethink the overall façade design and construction process to incorporate solar technologies from earlier stages, allowing for closer collaboration between the different disciplines involved. It was stated that integration has to be further considered by both designers and manufacturers, pushing for optimised mass production processes while minimising planning efforts. It was also mentioned that more design oriented tools are needed in order to bring architects closer to technical issues during early design stages.

Declared barriers not considered in the main categories were related with building regulations, conflict of interest between different stakeholders, building management problems during occupation, and insurance and liability aspects. Safety of the installation and definition of clear responsibilities in case something does not work as expected were particularly stated among these barriers. Nonetheless, these issues were not perceived as relevant as other previously discussed in this document.

3.2.1 Barriers to overcome in product design and development

As stated before, product related barriers received the most amount of total mentions. These barriers were further categorised for detailed analysis of the information, identifying key perceived aspects to guide future developments under the following topics: performance, technical complexity, aesthetics, durability and availability.

Figure 8 shows the subcategories of product related barriers, based on the gathered responses. Performance related barriers seem to be perceived as the most pressing to overcome, considering the amount of first and second mentions. Aesthetics is also seen as a relevant barrier, followed by the technical complexity of the systems involved. Lastly, the durability of the systems and product availability were also stated by the interviewees as barriers to overcome, although they were not perceived as relevant as the other barriers.

In general terms, performance related barriers referred to the need to improve the efficiency of current systems and components. It was also specifically stated that the integration of storage strategies is a requirement to allow for continuous operation, improving the overall performance while supporting a better management of energy flows.

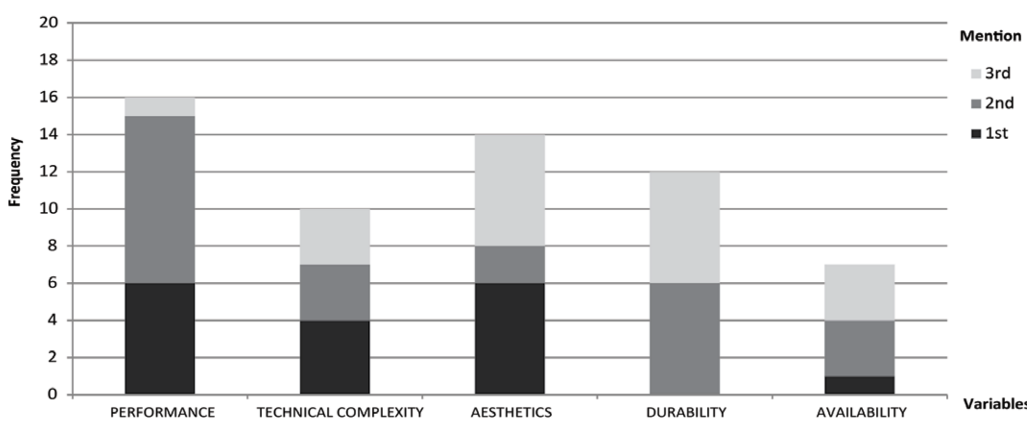

FIG. 8 Main perceived barriers related to current products

Regarding aesthetics, the answers were generally somehow vague, stating that the aesthetics of current components are something to improve, without further detailing parameters to be considered. Nevertheless, some specific aspects were mentioned by the interviewees, focusing on the necessity to allow for customisation in the design, promoting variety in the development of architectural products for integration. Furthermore, transparency was indeed mentioned as a factor to advocate for, minimising visual constraints in façade units. The findings from Task 41 support these results, especially in the case of solar thermal components. While it was found that both technologies need to be further developed to fully satisfy architectural integration requirements, Farkas and Horvat (2012) declared that photovoltaic applications present a higher degree of flexibility in formal characteristics, counting with more variety in terms of shape, colours, sizes, texture and possible translucency. Therefore, there is a particular need for incentives for manufacturers and a clear definition of aesthetical requirements, in order to develop architecturally appealing solar thermal components for façade integration; a fact supported by the work of Munari Probst and Roecker (2007) in the field.

Answers grouped under 'technical complexity' focused on problems associated with both overly complex assembly processes and operating modes of solar based façade components. In general terms, it was mentioned that further standardisation is advisable, without of course compromising design flexibility and customisation possibilities. It was specifically pointed out by some experts that the sum of modular components under a 'plug-and-play' connection logic should be the aspiration of future developments designed for façade integration, minimising assembly times and avoiding incompatibility issues between components.
The main issue regarding the durability of the systems was the need for maintenance activities which would have an impact on the operating cost of the building. The answers focused on two aspects as barriers for the integration of present technologies. First, durability of the components needs to be improved, while detailed information on the performance of aging components is needed to convince stakeholders and minimise economic risks. This issue is greatly connected with information barriers discussed above, being perceived as a knowledge gap within the performance of these technologies. Alternatively, it was also stated that even with enhanced durability, these components will need maintenance, so the possibility to easily maintain, repair or even replace several parts should be considered in the design along with end-of-life scenarios for the different components.

PERFORMANCE	AESTHETICS	TECHNICAL COMPLEXITY	DURABILITY	AVAILABILITY
Increase cost-effectiveness of components	Improve overall aesthetics	Avoid overly complex assembly and operation modes	Improve durability of components and systems	Develop array of products designed for integration
Improve/consider energy storage strategies	Allow for customisation of appearance	Promote modularity and plug and play components to ease integration	Devise long term maintenance strategies and end-of-life solutions	
Allow for energy management	Promote variety in design of components (form/materials)	Standardisation of components allowing for design flexibility	Allow for retrofitability	
	Minimise visual constraints			

TABLE 2 Key aspects to overcome for solar integrated product development

Finally, the responses categorised under 'availability' considered general complaints about the limited amount of suitable products for façade integration. In this aspect, it is greatly related to the other categories, which focus on particular barriers to overcome in order to provide new architectural products. It is the authors' opinion that this barrier is a secondary aspect, validated by the fact that it was not perceived as relevant as the rest by the interviewees. The offer of suitable products is expected to increase if product development overcomes the issues discussed under 'performance', 'aesthetics', 'technical complexity' and 'durability'; provided of course that there is demand for them by tackling non-product related barriers previously discussed in this document.

A summary of the main identified topics under each category is shown in table 2. The information in the table is presented in the form of recommendations to overcome the identified barriers and problems related to product development, based on the gathered responses. This is regarded not only as valuable practical information to inform future developments, but also as key aspects to consider for the evaluation of current solar technologies and components in terms of their suitability for façade integration purposes, based on how well they respond to issues related to performance, aesthetics, technical complexity and durability.

4 CONCLUSIONS

This paper discussed perceived barriers for façade integration of solar technologies, by presenting the findings of an open ended survey addressed to professionals with practical experience in design and development of façade systems. The survey aimed to identify the main perceived barriers, and key aspects to overcome, comparing the findings with previous experiences. Furthermore, special attention was given to product related barriers, drafting recommendations to drive future product development based on the gathered responses from experts in the field.

The vast majority of the interviewees (91%) believed that there is potential for façade integration, while 80% of the sample believed that there is current commercial demand for architectural products. Regarding perceived barriers, economy was the most pressing barrier declared by the experts. Furthermore, the cost of current systems, energy prices, and the lack of economic incentives were mentioned as key aspects to overcome within this category. Product related issues were also identified as highly relevant, based on the total amount of mentions. Lack of knowledge and information and process related barriers, although mentioned, were not perceived as pressing as economic and product related aspects.

Key issues to overcome within product related barriers centred mostly around performance, aesthetics and technical complexity of current systems and components, with durability and product availability aspects also mentioned. Relevant recommendations based on the gathered responses are the need to increase the cost-effectiveness of individual components, without compromising aesthetics of the product; and the need to design for integration, avoiding overly complex assembly and operation modes. Appearance customisation through a variety of components for façade design was encouraged in order to appeal to architects and clients, while modularity and the use of standardised elements and connections were advised to minimise construction and operation problems.

The findings presented in this paper fall in line with previous experiences on the topic in terms of the main perceived barriers. Additionally, the identification of key aspects based on the gathered responses allowed for a detailed discussion of product related barriers, in order to draft recommendations to inform future developments. Further research could be done to explore potential divergences in perceived barriers among different groups, expanding the sample to consider other contexts, backgrounds and roles not just in design and construction but also operation of these systems. Furthermore, the recommendations obtained from this study could be used to evaluate solar technologies in terms of their current suitability for façade integration. This would not only present the possibility to validate the findings against real experiences and commercially available products, but would also generate valuable feedback in the understanding of current limits for the development of solar integrated façade products.

Acknowledgements
This paper is part of the ongoing PhD research project titled COOLFACADE: Architectural integration of solar cooling strategies into the curtain-wall, developed within the Façade Research Group (FRG) of the Department of Architectural Engineering + Technology, Delft University of Technology (TU Delft). The research project is being funded through a scholarship granted by CONICYT, the National Commission for Scientific and Technological Research of Chile. The authors would like to thank all interviewees and especially the members of COST Action TU1403 "Adaptive Façades Network" for their support throughout the study.

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