Architectural Photovoltaic Applications
Lessons Learnt and Perceptions from Architects

Haghighi, Z.; Dehnavi, Mahboubeh Angali ; Konstantinou, T.; van den Dobbelsteen, A.A.J.F.; Klein, T.

DOI
10.3390/buildings11020062

Publication date
2021

Document Version
Final published version

Published in
Buildings

buildings

Article

Architectural Photovoltaic Applications: Lessons Learnt and Perceptions from Architects

Zoheir Haghighi [1,*], Mahboubeh Angali Dehnavi [2], Thaleia Konstantinou [1], Andy van den Dobbelsteen [1] and Tillmann Klein [1]

[1] Department of Architectural Engineering + Technology, Faculty of Architecture and the Built Environment, TU Delft, Julianalaan 134, 2628 BL Delft, The Netherlands; T.Konstantinou@tudelft.nl (T.K.); A.A.J.F.vandenDobbelsteen@tudelft.nl (A.v.d.D.); T.Klein@tudelft.nl (T.K.)
[2] Faculty of Architecture and Urban Planning, Shahid Beheshti University, Tehran 1983969411, Iran; Mahboubeh.dehnavi@gmail.com
* Correspondence: z.haghighi@tudeft.nl

Abstract: Researchers have reported that despite technological development in photovoltaic technology and substantial cost reduction, there is still a narrow interest in architectural photovoltaic applications (APA). Lack of interest is correlated to various bottlenecks, and one of them is a lack of knowledge among architects on the possibilities and approaches to adopt APA. In response to the issues mentioned, the aim of the research presented was collecting qualitative and quantitative information from architects as lessons learned and perceptions in regards to APA. In total, 30 architects with and without experience of using photovoltaics (PV) were invited and interviewed. They were asked about their experience, design and decision-making process with PV, their understanding of integration, and the decisive factors to use APA. The results showed apparent differences between the experiences and perceptions, and they highlighted the lessons learned from realized projects. The analysis of the visual implication of PV integration shows that, to the eyes of architects, integration of PV into architecture does not depend on the PV product used, but instead, that when PV is part of the design concept and design process, the outcome is seen as a meaningful integration.

Keywords: BIPV; PV; photovoltaic; integration; net-zero energy building; in-depth interview; design studies

Citation: Haghighi, Z.; Dehnavi, M.A.; Konstantinou, T.; van den Dobbelsteen, A.; Klein, T. Architectural Photovoltaic Applications: Lessons Learnt and Perceptions from Architects. *Buildings* **2021**, *11*, 62. https://doi.org/10.3390/buildings11020062

Academic Editor: Alessandro Cannavale
Received: 12 January 2021
Accepted: 2 February 2021
Published: 11 February 2021

1. Introduction

At present, there is a trend in the application, research, and development on the use of photovoltaic technology in the built environment. This trend began in the 1970s and has had its growth supported and hindered due to various external factors. Since its inception, a market has emerged for installing conventional and industry-standardized PV modules onto pitched or flat roofs, commonly referred to as rooftop applications or, as some researchers categorize, building-added photovoltaics (BAPV). In parallel, architects and other researchers urge development of exclusive PV products for building applications, which can be multifunctional and replace the conventional building materials known as integrated applications or building-integrated photovoltaics (BIPV) [1]. In the definition given by the EN 50583:2016 standard [1], "Photovoltaic modules are considered to be building-integrated if the PV modules form a construction product. Thus, the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product."

In response to climate change and international agreements to reduce carbon emissions, European countries are implementing some schemes to promote the use and application of photovoltaic technology within urban areas, e.g., to achieve nearly zero-energy buildings (nZEB) [2,3]. Particularity regarding nZEB [4], in additional to the measures for increasing building energy efficiency, the energy demand of the building should be supplied by renewable sources onsite or nearby. Nonetheless, many architects and designers do not seem to be interested in the appearance of conventional PV modules (black or blue cells and silver frames), nor in the approach of addition/attachment of PV modules to their designs [5]. During the last several years, technological advancement in PV technology and module manufacturing techniques allowed for the development of new PV products with various sizes and colors to increase the popularity of PV technology among architects [6]. However, despite the overall growth, cost reduction, market maturity, and commoditiation of conventional PV modules for large-scale and rooftop applications, the integrated products (BIPV) account for only 2% of all PV installed worldwide) [7,8]. The same report also indicates that 35% of these products, which were already available in their report published one year before, are no longer available, as the manufacturers failed to maintain their businesses.

In a survey conducted on the causes of the unpopularity of building-integrated photovoltaic products, issues regarding lack of knowledge and costs were dominant among the respondents [9]. In the framework of International Energy Agency (IEA) Task 15, building owners were interviewed to explore suitable business plans applicable to PV technology in the built environment [10]. According to another survey conducted about IEA Task 41 (concerning the integration of solar energy systems and architecture), after the socioeconomic aspects, which were perceived as a major hurdle, lack of sufficient architecturally oriented literature on the different aspects of photovoltaic technology was found to be the second most important barrier [11]. In various research articles focusing on the integration of PV technologies to the historical and monumental buildings, it has been highlighted that the legislative process for any changes in regards to aesthetic appearance and historical values has been addressed as another hurdle in addition to economic issues for adoption of PV technology to these buildings [12,13].

Throughout the years, there have been many instances of architects using PV technology in their projects. They used different types of PV products and implemented them using different approaches. In literature, despite the effort made in IEA tasks [14], we have found no document addressing the experiences of architects with the focus to use of PV products in their designs [15]. Nonetheless, in order to meet the mentioned sustainability targets within the built environment, we need to identify the bottlenecks and challenges in the decision-making process, and to learn the expectations and considerations of architects as the lead stakeholders in design and decision-making processes.

Therefore, considering the gap in knowledge regarding the experiences of architects from realized projects with PV, the challenges and considerations to work with PV mentioned in literature and the relevance of knowing architects' opinions about the use of PV technology in buildings, we conducted an explorative study aiming to collect a mix of qualitative and quantitative data from architects and other designers. In order to achieve this, we interviewed 30 architects with and without experience in using PV technology. The aim was to find information regarding the design process, challenges in the use of PV products, bottlenecks within decision-making, and the overall experience. In addition, the authors aimed to see if "integration" as a concept holds any visual implication to architecture and if a definition of "integration" could be made, including design specifications.

In the following sections, the method to set up the interview and the recruitment of interviewees is explained. Subsequently, in this paper, the findings from the interviews regarding the design and decision-making process and the aspects influencing the integration of PV in a project are presented and interpreted. Finally, we conclude with insights about the further implementation of the lessons learned.

2. Methods

The main objective of this study is to document the experiences and perceptions of architects and other designers regarding architectural photovoltaic applications (APA). The research team has opted to apply an in-depth interview method to collect and explore the architects' perspectives on the topic and to acquire more in-depth insight compared to what is available in literature. This method has recently been used by several researchers and is shown to be a practical approach for collecting qualitative data, primarily when experts and experienced respondents are targeted. For a similar topic, the adaptive façade, Attia et al. [16] used this approach and concluded that the in-depth interview method provided comprehensive information for understanding the experiences and expectations of the respondents. In addition to the in-depth interview, one segment of the study aimed to collect quantitative information when respondents were required to rank important factors in the decision-making process.

In accordance with [17], based on the three types of interviews, an open-ended nature was selected for the in-depth interview regarding qualitative data. Since the respondents were asked about the objective facts of a subject as well as their opinion, they were requested to propose their insight on certain occurrences. Such an approach allows the interviewer to use such propositions as the basis for further inquiry. In addition, in certain parts of the interview, some of the questions were designed to be responded by a group of predefined answers. This quantitative data helped the research team in approaching a more straightforward conclusion regarding the effects of certain factors in the decision-making process. This approach allowed us to gain broader insight into the results by being able to extract two types of data from one source. It is to be noted, however, that in this model, the two data types are not influenced and are not related to one another: they exist parallel to one another and have separate methods of interpretation.

As shown in Figure 1, the interview process is composed of three steps; in chronological order, these are: research design, data collection, and content analysis.

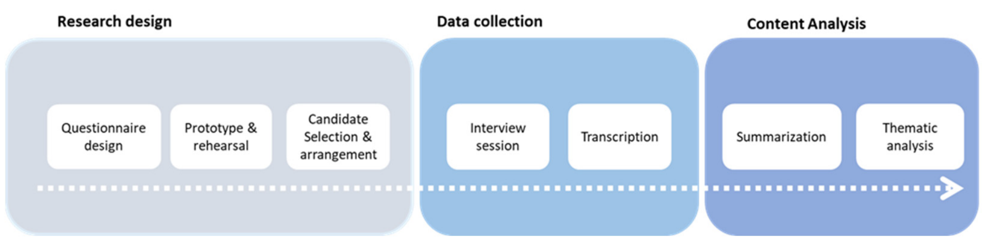


Figure 1. Interview process by research design, data collection, and content analysis.

2.1. Research Design

In order to design the framework for the in-depth interview, the main areas and topics that had to be covered were drafted and, accordingly, a list of questions was framed. These questions were clustered together into four broader thematic sections:

1. Experiences and lessons learned,
2. Insights and perceptions,
3. Understanding integration,
4. Decision-making factors.

In an early stage, the research team decided to divide the interviewees into two groups, A and B. Group A consisted of architects who have previously used PV technology in their design. Group B consisted of architects that have not yet managed to use this technology in their design. This division was important because we could include both experiences that come out of the realized project and perceptions from the architects who yet have not yet used the technology. Therefore, a more comprehensive range of information could be collocated, and comparison in the received responses could be made between the two groups. It is a common approach in interview methods and known as control group approach [18].

The interview was divided into three parts (Figure 2). The first two parts were aimed at collecting qualitative data, whereas the third part collected quantitative data. This approach is known as the mixed-method approach [19] and proved to be useful and relevant, as we needed to collect qualitative data for objective thoughts including experiences, perceptions, and understandings in the first two parts. In the last part, we needed to be able to collect quantifiable information. This approach allows the researcher to gain broader insight into having two types of data instead of one. Although these data are not related to each other in this model, they stand side by side and have their method for interpretation [19].

Figure 2 presents the three steps designed in the questionnaires.

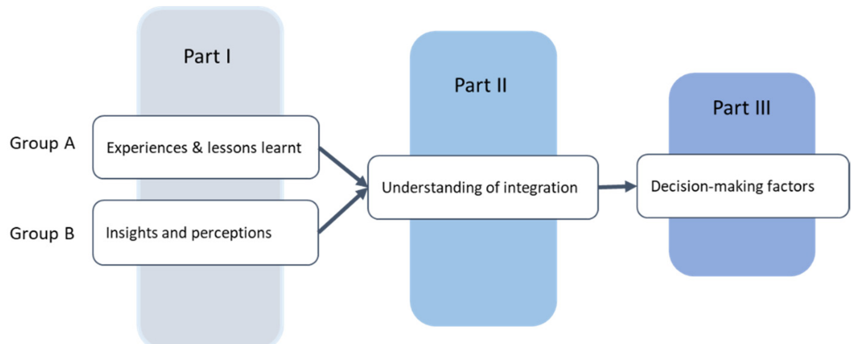


Figure 2. Stages in the questionnaires.

In part I, each group was questioned differently.

For Group A, the questionnaire covered the following aspects:

- Project background, motivation and key drivers
- Design process with PV
- Lessons learned and takeaways

For Group B, the questionnaire covered the following aspects:

- Drivers and barriers
- PV and architectural design
- Expectations of the PV product

Sometimes, similar questions were asked to both groups. However, it was essential to distinguish the data that were generated from the experience of an architect with specific cases, or the data that reflect the architect's insights and perceptions.

Part II was similar for both groups and revolved around "understanding of integration". In this part, it was requested that interviewees outline their verbal understanding of the implication of the term "integration". They were then presented with the images of six projects realized with different design approaches to PV technology or PV configuration and then were asked whether for each project they think PV is "integrated" or not, and questioned about the reasoning for their answer. Finally, the architects were asked which one(s) among the projects best describes the best example for the definition of integration.

For Part III, also similar for both groups, a list of predefined influencing factors in decision-making was designed. Interviewees were asked to indicate the relevance of these factors, based on a scale ranging from 0 to 9.

The questionnaires were tested in a series of pilot sessions conducted among peers and members of the research team, aiming to simulate an interview session, resolve any potential ambiguity in the questions, and refine the process based on received feedback.

As the final stage, the research team assessed the relevance and clarity of the questions in an iterative process. Subsequently, a definitive list of questions with an ordered sequence was prepared. This list is available in Appendices A and B.

As per official data collection requirements at the Delft University of Technology (TU Delft, The Netherlands), the interview documents, including questionnaires and procedures of the interviews, were presented to TU Delft Human Research Ethics Committee (HREC) and received approval.

In order to recruit suitable interviewees, the research team took a purposive sampling approach [18]. Thus, candidates were consciously selected and invited. For Group A, a previous study by the author on 30 realized projects was used as a baseline. In the study mentioned, some categorization was made by the design approaches to PV, and each project was studied through the lens of four different parameters: 1. visibility (of the PV module) in overall design, 2. mounting strategy, 3. level of adaptation, and 4. additional functionality. Therefore, one or two sample cases from each category were selected, and the architect was invited to participate in the interview. The research team also invited a few other architects/designers whose projects had been highlighted in professional networks because of the novelty of the PV products they used or because of the new approach they had implemented.

For Group B, architects who had no experience of working with PV technology were targeted. For the selection of suitable candidates, the research team tried to include architects/designers from construction typologies differing in function and sector. The categorization of building typologies made by Euroconstruct reports was used [20], and according to each typology, different candidates were invited. For this group, a clear preference had been given to architects/designers who were available and accessible via the professional network of the research team, some of whom professionally linked to Faculty of Architecture at TU Delft.

2.2. Data Collection

In this study, 30 interviews were conducted from October 2018 to June 2020 in five different countries in addition to national visits within the Netherlands. The interviews were recorded with a digital voice-recording device (a Sony PX470, Sony, Minato City, Tokyo, Japan) with the consent of interviewees. The duration of interviews ranged from 50 to 75 min. From the 30 interviewees, 15 were architects with one or more projects realized with PV and 15 were architects without such a project. In the following parts, the interviewees will be addressed by their number from the table in Appendix C.

According to Attia et al. [16], transcription is an essential and inevitable step for any form of analysis on qualitative content [19]. In this study, manual transcription methods were used for the majority of the interviews, and some automated transcription software was tested. For this research, the "Google live transcription" mobile application (Google, Mountain View, CA, USA) was used for some of the interviews. This Google app is able to transcribe with high accuracy; however, it has its shortcomings related to the exportation of transcribed texts. Therefore, a manual review on the automated transcription was also essential to prevent any errors or missing parts.

2.3. Content Analysis

The step after transcription consisted of summarizing each interview and highlighting common areas, topics, and themes that were mentioned frequently. According to the research goals and research questions, relevant themes were selected as basis for the analysis. This is known as the deductive approach, in which the data are analyzed based on predefined themes [19]. A spreadsheet was created containing keywords and a summary of the interviewees' answers. Afterward, the research team analyzed the different viewpoints and experiences of the interviewees concerning each topic and produced an interpretation and overview, including some quotes from the interviewees. The findings were also clustered in four themes mentioned earlier; these are presented in the following section. The results have been summarized in tables in the beginning of each section. Each table includes the finding and remark that was discussed, reference to the interviewees who made that point, the observation of the authors, and quotes that support and complement arguments.

3. Results and Discussions

In this section, the findings and analysis of findings are presented under the four thematic sections that the interview was based upon. Under each theme, there are subsections that focus on certain topics discussed with the interviewees. In addition to the results of the analysis and quotes from interviews, each subsection presents the interpretation of the research team.

3.1. Experiences and Lessons Learned

This section presents the findings and information collected from the first 15 interviewees, who had applied PV in projects. In these 15 interviews, the respondents were asked to share their experiences of working with PV technology in their project. The results, presented in Table 1, have been classified into three subsections: (1) project backgrounds, motivations, and key drivers; (2) PV and architectural design; (c) lessons learned and takeaways.

Table 1. Experiences and lessons learned.

Project Backgrounds, Motivations, and Key Drivers				
Topics		**Findings**	**Interviewee**	**Observations/Interprets**
Motivations and key drivers	I.	Complying with external incentives—Harvesting on-site renewable energy to address sustainable development goals	4, 6, 8, 12	• Photovoltaics (PV) were found to be the best way to produce energy on-site and meet SD goals
	II.	Green architecture—Concept and potentials for the use of technology	1, 3, 5, 7, 9	• Considering PV from early stages of design is a challenging task—making a balance between form and function
	III.	Marketing and demonstration—The building owner's image + education + testing and promotion of photovoltaic businesses	1, 2, 10, 11, 12, 13, 14, 15	• PV is perceived as a sign for sustainability, and in the majority of cases, this aspect helped with its acceptability for investors
	Quotes: • Architect 1: "We wanted to make people believe that PV panels are a material that has no problem being used in the façades, that they can look normal and working with them is quite easy." (referring to II and III) • Architect 3: "The site allowed having plenty of south-facing surfaces and was ideal for capturing solar energy before they cause overheating in the building." (referring to II)			
Design process and PV				
PV in the design concept	I.	There were intentions to show PV in the project, either by the architect or owner	1, 3, 4, 6, 7, 8, 12, 13	• Condition of visibility of PV system in design concept is linked

	II.	Specific PV product was chosen by the project owner, but the architect used creativity to blend the modules into his design concept	11, 15	to the original motivation of the project and also the general viewpoint of the architect in regards to the having exposed or hidden building services
	III.	Preferred to have PVs invisible or not as part of the design concept	5, 9, 10, 14	
	Quotes: • Architect 1: "PV is like a normal material, and it is not important making it visible and expressive." (referring to I)			
Design process with PV	I.	PV product was considered from the early stages of the design process.	1, 2, 3, 4, 5, 7, 9, 15	• It can be seen that applying PV in a building requires precautions that an architect must consider in the early stages of the design. • When PV came late in the process, the possibilities and unification between the PV component and building design became limited and challenging
	II.	Surface for applying PV allocated during early phases, but the modules are chosen later	6, 8, 10, 12, 13	
	Quotes: • Architect 9: "With the intention of working with holistic sustainability concepts, you can't develop a building without good integrated design process, and you need to start from scratch with all the advisors." (referring to I)			
Building surface to apply PV	I.	Façade used when the roof space was not enough to supply the energy demand	1, 7, 8	• Based on local conditions, the motivation, and initial design concept, the architect opted to use PV on different surfaces in the buildings. Such a decision heavily influences the design concept of the building and the outcome of the projects.
	II.	Sloped roof or façade used in projects when visibility and external communication about the PV was important	3, 4, 6, 11, 13, 15	
	III.	Roof space used for external communication in X-large scale projects	5, 12	
	IV.	The designer opted to use surrounding buildings or add additional structure to apply PV due to various reasons	2, 3, 4, 9, 12	
	Quotes: • Architect 2: "A great solution for dense urban areas with limited surfaces and municipal restrictions for changing the building façade is to add additional floor level with a PV system, which can increase the building service area and is a sweet incentive for investors." (referring to IV) • Architect 3: "The design concept allowed the building to receive light from three directions, and the use of a shading component to control the heat gain in the design was essential. The owner wanted to keep the façade opening as transparent as possible for outdoor vision, and therefore we designed an additional component with PV to act as shading". (referring to IV)			
The PV product applied	I.	Certain PV products were dictated by the project owner/developer or chosen by the contractor	3, 10, 11, 13, 15	• In projects when architects had some freedom to choose the product and customize the existing product, they experienced many limitations, losses of efficiency, and a higher final cost.
	II.	Architects were involved in the design and development of the PV product	4, 7, 9, 14	

	III.	Some architects urged for custom sizes, colors, or transparency, which was not either possible or was too expensive.	5, 8, 13	
	IV.	In some location, additional tests and certifications for safety issues were needed	9, 12	
	Quotes: • Architect 13: "We spent a long time to find a supplier of nonstandard PV in our market, we found very few, and they mostly had products for roof application. During the construction, we changed three times the supplies as the mounting system and modules were not reliable and safe for façade application" (referring to III)			
Lessons Learned and Takeaways				
Experiences	I.	Overall positive experience with working with PV, success for the firm	All except 4	• Despite the challenges mentioned, the majority found it a great experience which made them recommending it to their peers and redo it on other projects
	II.	They are already busy with more projects with PV and definitely would do it again.	1, 9	
	III.	They would have done it differently or would not advise to do it again as it is	4, 8	• When the driver of the project was the energy yield of the system, making a balance between the design and energy yield were a challenge.
	Quotes: • Architect 6: "We should use PV and other energy-producing technology on a larger scale; doing it in only a few buildings is not functioning well; we should see it in more buildings." (referring to II) • Architect 7: "Working with PV has been easier than expected, more predictable, not very different than with a lot of more construction material". (referring to I and II) • Architect 14: "We faced many problems during the process but after the inaugural of the building, we received huge interest and requests from visitors from all over the world to visit the project. Although the PV modules are not visible, many people want to know about it and see it. This is what we are proud of." (referring to I)			
Challenges, watch-its, and take always	I.	They faced design challenges working with standard modules which limited their design and possibilities	8, 12	• These challenges and the final result of projects show how sometimes a challenge can be turned into an opportunity; that's where an architect's role in this process became evident. • How small considerations within the design of the system can highly influence the final performance of the system, and indeed knowing them and considering them from the early stage of the design process is key to success.
	II.	In the façade application, making a balance between openings and PV—Window to wall ratio	6, 9, 14, 15	
	III.	Accessibility of PV systems for maintenance and cleaning and replacement	3, 4, 8	
	IV.	Safety consideration with PV modules and supporting structure	4, 9	
	V.	Modules tilt and angles—for optimal yield in summer and winter and prevent overshadowing of the modules	1, 3, 5, 9, 14	

VI.	Required space for ventilation and cables of modules while being weather-tight	1, 5, 8, 11, 12, 14

- Architect 14:"Having the maximum number of PV on the façade and enough light during all seasons to have a good learning environment for the school was a challenge". (referring to II)
- Architect 4: "Because of fire safety issues, we were forced to put frames all around the panels and two brackets to support the frames". (referring to IV)

3.1.1. Project Backgrounds, Motivations, and Key Drivers

The overall result of interviewing the first group shows that each project had a different starting point, which eventually influenced the outcome of the project. The interviewees were asked to state the concept behind each project and outline the motivation and the role of the stakeholders in the deployment of PV in the projects. Regarding initial motivations to use PV in the project, various responses were received.

The most common reason mentioned for using PV was producing on-site renewable energy to address sustainable development goals in the built environment and to comply with external incentives. They argued that even energy-efficient buildings require large amounts of energy to operate, and in order to meet these demands, photovoltaic technology was found to be the best way to produce energy on-site.

Another motivation mentioned by two of the interviewees is the potential for harvesting energy in the design concept and the tendency of the design team to work with principles of green buildings.

Other motivations include marketing and demonstration, the building owner's image, and the testing and promotion of photovoltaic businesses. In these projects, the amount of energy that could be produced by the PV system was considered 2nd or 3rd priority: external communication was the key driver. Looking at the stakeholders, in the majority of cases, the project owners showed interest in using PV and requested its inclusion in the project. In others, the architect and design team convinced the client to utilize the technology.

To conclude, different motivations and starting points to use PV have directly influenced the design process, design concept, and decision-making process. As indicated, to use PV in the projects, building owners were the most influential stakeholders in the decision-making process, followed by architects.

3.1.2. Design Process and PV

A. PV in the design concept

The conventional photovoltaic panel is an element with a specific appearance, which often makes it difficult for architects to integrate PV into their designs. Nonetheless, there are also products in which PV cells are invisible, as defined by [21]. Some of these were used to realize some of these projects. During the design process, it is essential that the design team and project owner decide about the visibility of PV panels in the building to the eyes of visitors. The interviewees were asked whether having PV visible or concealed in their design was intentional and whether this was a part of the design concept or a product of circumstance due to limitations with PV products available at the time.

The majority of interviewees had chosen to have PV visible, but each had their reasoning and motivation. In some cases, such as with interviewees 15 and 11, specific PV products, conventional with visible cells, were chosen at the behest of the client, but the architect managed to implement them into the design concept through creative innovation. There were architects who preferred to have the PV cells invisible, or not to take PV as part of design concept; they were not interested in showing or exposing PV in their design.

These experiences show that the condition of visibility of a PV system in the design concept is linked to the original motivation of the project. It also indicates the viewpoint of the architect in regards to having exposed or hidden building services.

B. The design process with PV

The moment to bring PV into the design process is an important factor and influential for the final design concept. In this part, interviewees were asked to mention when they introduced PV during the design process.

According to the interviewees, in spite of diverse outcomes and a symbiotic relationship of PV with the design, the idea of using PV came into the design process at an early stage of the concept development. These interviewees believe that it is necessary to think about PV from the beginning of the design process, as they want the PV to be felt as a part of the architecture and not merely as an add-on. In cases where PV took over some other functionalities in the building, it became even more vital to consider PV application from the beginning of the design process.

The significant difference was whether the team also decided at the early stage on the type of product they were interested in or planned to use. There were many projects in which the surfaces onto which the modules were to be installed had already been allocated in the design concept, but in which the electrical team or contactor later detailed it with conventional and cost-effective modules with optimal configuration of the module. In these projects, the modules were relatively separated from the design concept.

To conclude, in most cases, PV was considered in the early decision-making process, which reflects its involvement in the overall building design. It can be seen that applying PV in a building requires precautions that an architect must consider in the early stages of the design. Therefore, when it came late in the process, the possibilities and unification between the PV component and building design became limited.

C. Building surface to apply PV

In building applications, in order to capture energy from the sun using photovoltaic panels, these are commonly placed on the roof or façade. Embedding panels on the roof or façade is dependent on various factors. For many architects, the default place to put PV was the roof surface. One of the factors that led some of architects to consider using the façade for PV application was the amount of energy that the building needs to produce.

Some other architects used PV on a sloped roof and on the façade for external communication. According to interviewee 6, the project was big enough to allocate PV modules on the sloped roof, based on the function of the project: the design team placed the PV system in such a way that PV could be seen from the ground level to demonstrate the application of sustainable energy in their building. In large-scale projects, with formal design concepts, PV installation was also done on the roof area for external communication. Examples of these can be seen from the projects discussed with architects 5 and 12; in these projects, the roof area supplies only a portion of the energy demand, but the PV modules are not visible to pedestrians. In the project discussed with architect 10, the design team had also installed PV modules on the roof area, as the owner clearly urged to hide PV from visitor's view; therefore, small PV arrays had been placed on a canopy installation on the roof area, which was fully hidden and not accessible to visitors.

When the service area on the roof was insufficient, the building owner considered adding more space by renting roof area of surrounding buildings and asked the design team to include an additional structure and space in the design concept. For the project discussed with architect 2, site restrictions led the design team to arrive at a unique approach. They designed a pavilion-like additional structure on the roof to hold the PV system. A similar approach had been used by architects 3 and 4 for a newly built project. In these two examples, an additional structure was designed on the facade to hold the modules. These architects ensured that these additional structures became a part of their design concept and were not just add-ons.

To conclude, based on local conditions, the motivation and design concept, the architects opted to use PV on different surfaces in the buildings. Such a decision heavily influences the design concept of the building and the outcome of the projects.

D. The PV product applied

The PV product selected for the project has a strong influence on the final outcome of the project. For this section, we asked the interviewee to outline what the decision-making process behind selecting the PV product was, how they found the product, and what their expectations were.

As discussed earlier, in some of the projects, the use of certain PV products was dictated by the project owner/developer, so they played a key role in product selection. In other cases, the main contractors had already selected a product and provided it to the designer; the architects did not play a role in choosing the product.

For the projects where the architects had to select a product, they tried to find the product through various means—for example, by going to conferences related to solar power, searching the Internet and inviting PV manufacturing companies to acquaint themselves with their products. Such close contacts allowed the design team's involvement in product development. For these projects, a certain degree of modification and customisation was possible, but for some, this only remained a wish. This was the case with interviewee 1, who asked for custom-sized modules and who preferred thin-film technology; the customization was not financially viable. In the cases of architects 4, 5, and 8, who wished for transparent glass-like PV panels, these were not available to them at the time. Architects 8 and 13 wished for a larger variety in color; however, such a product would have less efficiency and, therefore, would be unfavorable to meet the project's energy target.

To conclude, there are many new possibilities with the customization of PV modules for fitting the design concept better; however, applying these changes to the product will increase the panel's price, sometimes influence the accessibility of the modules for maintenance, and finally increase the operation cost of the building, which overall will make the owners and architect hesitant to opt for them.

3.1.3. Lessons Learned and Takeaways

A. Experiences

Overall, all architects interviewed, barring architects 4 and 8, were positive about their experiences and considered working with PV to be a success. Some, i.e., architects 1 and 9, mentioned that the projects discussed were not their first and would not be their last. Some of them were involved in other projects utilizing PV at the moment of the interview.

Opposite to the positive stories, architect 4 was doubtful about the effectiveness of the technology in Central and Northern Europe because of lower solar radiation. Architect 8 had utilized a PV system in their project but received negative feedback from the news and media, as they found the design of the PV system ugly. He explained that because of energy efficiency ambitions for the building, they needed to produce the entire energy demand of the building; as it was a social housing project, they were forced to keep the price as low as possible and work with the highest efficiency and cheapest PV module. This resulted in a building that appeared to be fully covered in PV cells. He mentioned this was a challenging project as they were limited in terms of design.

To sum up, the architects' experience shows that decision-making included many important issues and some watch-outs that had to be considered. Most of them consider that experience positive: a successful project within their portfolio, which they are proud of.

B. Challenges, watch-its, and takeaways

In this part, we asked the interviewees to share their experiences, lesson learned, challenges they faced, and considerations for applying PV in their projects.

Projects in which a certain amount of energy production was targeted suffered from changes to the PV module. Striking a balance between the aesthetics of the system and energy yield was mentioned as one of the most challenging parts of using PV in the building. Another challenge lay in the design of openings in combination with PV modules in the façade. Some architects took measures to solve this problem; for example, architect 4 stated that "The building was designed with the idea of leaving the façade free to admit daylight and look better, so the PV was installed with a space of 1.2 m in front of façade."

One other important issue mentioned was accessibility for maintenance; all interviewees stated this as a factor that needs to be considered in the design process. The panels must be designed and installed on the building in such a way that they can be easily replaced, when necessary.

The next consideration is about the structure that is supposed to hold the panels. In addition to having sufficient strength to hold the panels, this structure must also be completely safe and comply with fire safety codes.

Another important point of consideration is a gap for cabling and for ventilating the module. Without proper ventilation, the panel's temperature will rise, affecting the energy yield and also transmitting the heat into the building. In addition, weather robustness and rainwater tightness of the system was a challenge that needs detailed engineering.

In order to maximize the energy yield, the PV panel needs to be at a certain angle, so architects must consider this when placing panels on roofs or facades while avoiding overshadowing of the PV module. Some architects, such as 14 and 9, played with this feature in the façade application and designed a vibrant 3D façade system.

To sum up, working with PV as with other technologies and materials requires consideration with regards to design, technical aspects, safety and operation. Many of these considerations were mentioned by the interviewees. These can be valuable takeaways for a targeted audience of this research.

3.2. Insights and Perceptions

In this part, sets of general insights provided by the interviewees, independent from any specific project, are presented. Due to the nature of the questions, said insights are mainly from Group 2; however, general input from Group A is also considered. The findings have been analyzed and clustered in Table 2 as follows: drivers and barriers, PV and architectural design, and expectations of PV products.

Table 2. Insights and perceptions.

Insights and Perceptions				
Topics		**Description**	**Interviewee**	**Observations/Interprets**
Drivers and Barriers	I.	External incentives and regulatory frameworks were perceived to play a crucial role	8, 28	• By nature, architects with no experience working PV have more doubt to use the technology, and external pressures can be a good instrument to make them try this technology
	II.	Investment needed for PV system + higher operational cost of the building	22, 25, 28	• From the architects who have not used PV in their projects, more questions, doubts, and considerations were raised. The majority of these concerns are valid and
	III.	Short-term interest in the buildings makes investment for PV difficult for developers	12	

	IV.	Doubts and unclear guidelines during the use phase of the building and PV system—who is responsible for maintenance and cleaning—renter, owner, owner's association, etc.?	14, 17, 18	showed the complexity of applying PV technology in the building, but it seems that some of them can be handled easier than perceived by some architects
	V.	Lack of diverse products with reasonable price with reliable after-sale services	12, 15, 24	• There are some variants of PV products with competitive prices in the market, but they are struggling to find their rote-to-market.
	VI.	Lack of knowledge and experience among architects and designers	24	• A guideline for the architects, including all the steps needed for the use of PV in a building, can help to address this issue.
	VII.	Shorter service life of PV modules compared to buildings difference between	6, 12	• Considering the 50–75 years lifespan of the average building in Europe, and the 25–30 years for a PV module, the product will need to be replaced at least once
	Quotes • Architect 18: "In the dwelling, logically, the housing associations would be responsible for PV maintenance; maintenance is one of the reasons why architects often put PV separately on the roof." (referring to V) • Architect 24: "PV was not really made for façade application; it is tough to find the right product to make a façade. With PV, the building would look black or blue, and people would not like it." (referring to V) • Architect 16: "Designers may work with this material in order to see what specific qualities it holds or what potential it has. Photovoltaic technology is quite advanced, yet architecturally, PV products are a bit clumsy, and more experimental product development is needed." (referring to VI)			
PV and Architectural Design				
Design Process	I.	The earlier PV comes into the design process, the better it would fit into the design concept.	16, 22, 25, 26	• A conclusion can be derived that the question of where to apply PV is relative to the question of when to think about using it and which product to use.
	II.	PV could always be considered even after finishing construction, such as roof application or when you want to use it as an external shading component	14, 24, 28	
	Quotes • Architect 21: "Instead of putting a solar panel on a sloped roof, which is not nice, or printing it as a pattern on the facade, the designer should start working with it during the design process and consider its size and texture when designing the façade". (referring to I) • Architect 28: "In some buildings, PV comes last in the building process; so, it can be added on. Moreover, if the PV modules were not integrated into the building, such as by placing it on the roof, it's easily able to be replaced or upgraded." (referring to II)			
Building surface to apply PV	I.	Application of PV on the roof is more practical and easier with installation, maintenance, cleaning, and replacement	5, 12, 25, 28	• It is perceived that the easiest option for PV is using it on the roof space, and the demand for higher yield seems to be the main driver for thinking about other surfaces. The designer can be pragmatic about using a standard low-cost, high-performance product.
	II.	When applying PV on a facade, it is more important to be careful with design and aesthetics; in an urban area, it is difficult to integrate it as part of the architecture	10, 29	

	III.	In buildings that the PV is not part of the main concept, it comes last in the design and then it is placed on the roof	26	There is a minimal complaint regarding the ugliness of the standard panels, as they are only seen from a top-down view.
	Quotes • Architect 25: "Based on calculations when there is enough space on the roof, the designer puts the PV there. This is the best solution if the client thinks that the PV panel is ugly." (referring to I) • Architect 27: "We believe that the façade should not only be utilized as thermal insulation for the building but also to generate energy and communicate and interact with the city and environment." (referring to II) • Architect 28: "When displaying a building's ability to produce energy is important, a transition occurs in the design where PV is slowly removed from the roof and comes to facades." (referring to II)			
Energy yield vs design	I.	Making compromises and adaptation is a part of the responsibilities of the architect and, as they were used to it, found it easy to do so	14, 16	• Creating a balance between the energy yield and aesthetical values is directly linked to the overall cost of the system, which is one of the bottlenecks with the use of PV technology in rchitecture.
	II.	If PV considered from early staged, the adaptation of design would be needed	23	
	Quotes • Architect 16: "Architects modify materials in order to make it fit in with the design; adapting a design depends on what kind of limitations the architect is confronted with". • Architect 23: "Architects have to be creative when selecting a technology and adapt it from the beginning and make it simple in order to encourage others to use it".			
Visibility of PV in design	I.	It depends on the design concept and it is the architects say to hide or expose PV	15	• Architects opinion on the visibility of PV is diverse, and it is difficult to make a clear statement on their preferences. However, it can be concluded that if the PV product is tangled as part of the design concept, there are fewer concerns with the visibility of the system.
	II.	When the design is strong enough, and panels are a part of the design, it is fine to have the PV visible as a seamless building service.	18, 28, 30	
	III.	Visibility of the PV system is important because it is a new technology and that the building should achieve a unique look using it	7	
	IV.	It is up to the client or project owner to decide on the visibility or when the project's concept centres within the use of green energy and sustainability	20, 24	
	V.	Within the intercity refurbishment projects with municipal restriction, we need to hide PV in the design concept	24, 26	
	Quotes • Architect 16 mentioned "Of course people often try to say that if I invest in it, I want to show the world that I am doing the right thing. That is good for the first phase when people want to demonstrate that they are responsible citizens of this planet, but that's not the end goal. The end goal should be that PV becomes an evident element in a building and that, for me, it is not necessary to expose the fact that it's a PV panel." (referring to IV) • Architect 14: "The solar cell should be considered as part of a family. Designers must view it as a group of words that must be assembled into a sentence by the architect. It must fit into the systematic process of the project, and the system's productivity has to be in balance with its beauty. It is an interesting challenge."			

Expectations of PV Products	I.	Architects are limited to what suppliers possess, which are modules that come in either black or blue with a thick aluminium border	28	• A majority of these architects were not aware of new technological developments within PV manufacturing. This indicates a large gap between science and the market. Others who were aware of recent advancements mentioned that these developments increase the overall cost of the PV system and make it less appealing for investors.
	II.	Semicustomisable PV module can be a good solution—PV modules where generic modules are produced using a standard process but can have additional features added to them after the order.	23, 30	• This suggestion seems to be ideal for both parties to maintain the standard production line and allow particular optional feature upon delivery
	III.	Among the participants, around 17% preferred standard PV modules, 40% asked for customized PV modules, and around 43% mentioned that both types (standard and customizable) products should be available	-	• Based on the design concept and role of PV in the project, both standard PV modules and customizable systems are needed.
	IV.	Interviewees express the important physical features of a PV module: • color 96.1% • transparency 84.6% • size 76.9% • reflectivity 76.9% • flexibility 42.3% • weight 30%	-	• The industry should seek to develop and manufacture standard PV modules that come in a diverse range of sizes and colours that make it easier for architects to utilize them in their designs
	Quotes • Architect 1: "This is a problem shared with other building materials, too; standard varieties exist that are cheap and always in stock, but once you need to deviate from the standard model, cost and manufacturing time increase dramatically." (referring to I) • Architect 30: "Photovoltaic panels are a new technology, and are going to improve in the future. PV will improve and arrive at a level where clients no longer argue with architects on why PV is included in the design, but rather why it is not included."			

3.2.1. Drivers and Barriers

In the first step, interviewees were asked what factors could drive them to utilize PV in their projects. The respondents outlined their perceived obstacles and bottlenecks in their decision-making.

External incentives and regulatory frameworks were perceived to play a crucial role in most cases of adoption of PV in buildings. Architect 28 believes that government incentives and legal frameworks for promoting PV in buildings are the only way to convince investors to use PV.

From the other side, the majority of architects mentioned that the investment needed to use PV had been the most significant consideration. Not only the cost of the PV panels themselves but also the cost of labor required to install and maintain them will increase total building costs. This is especially true when an architect suggests involving nonstandard PV in their design; decision-making for the investor becomes much more difficult as the payback period is extended.

Architect 14 also mentioned hindrance factors for architects surrounding legal issues in terms of responsibilities and guarantees regarding the PV product. Some doubt was raised several times by the architects about the responsibility for cleaning and maintenance of the module: the building owner, building operator, or tenant. This issue influenced the building design; sometimes, the architect preferred to install PV on the roof to solve these problems.

Lack of diverse products with reasonable prices was also mentioned as a hindrance. The image of the current average PV is the stock-standard modules that are used in large-scale solar parks, which also find popularity with single-family houses with pitched roofs. Considering this perception, several architects indicated that the issue lies with the lack of products. The research team reflected that various products are available, but due to a lack of knowledge, these technologies are perceived as expensive and not commercially available. This perception includes lack of trust and credibility regarding quality assurance of PV products.

Lack of knowledge and experience among architects and designers is mentioned as another limiting issue. Despite the fact that the electrical and technical design of the system would be handled by an engineering team, similar to other areas of building design (e.g., structural, mechanical), architects need to understand and be familiar with the basics of the system in order to have a leading role in the design and decision-making process. A guideline for architects, including all the steps required for the application of PV in a building, can help to solve this issue.

To sum up, from the architects who have not used PV in their projects, more questions, doubts, and considerations were raised. The majority of these concerns are valid and showed the complexity of applying PV technology in a building. However, the architects who already had adopted this technology raised fewer of these challenges. It means some of the challenges can be handled easier than perceived by some architects. On the other hand, the complexity to implement PV technology in the building is still evident. This will be especially true if it is to be a part of the building system itself. This influences architects to keep PV as an independent system, treating it as an add-on to the building, in order to ease the difficulties.

3.2.2. PV and Architectural Design

A. Design Process

While there was no mutual consensus among the respondents, there was an apparent belief that PV should be introduced as early as possible in the architectural design process. Such an approach matches with the responses received from Group A.

There were, however, those opposed to this. They argued that they could always consider using PV even after finishing construction, such as a roof application or an external shading component.

Such polarized opinions on this issue show the interrelations and complexity of decision-making, such as some architects linking the question where to apply PV to when to consider using it. These findings verify that there is a direct link between the moment when PV is introduced to the concept and design process, the suitable PV product, and the surface used for the application of PV.

B. Building Surface to Apply PV

On the question of where PV should be installed, many interesting ideas were posed. As mentioned previously, some architects insisted on utilizing the practicality and ease of installation when the PV module is mounted on the roof. Based on the responses received, in the situation that PV is placed on the roof, the designer can be pragmatic about using a standard low-cost and high-performance PV product. There is minimal complaint regarding the ugliness of the standard panels as they are only seen from a top-down view.

In contrast, concerns arise when the PV modules are placed on the façade, as these are difficult to blend as a part of the architecture. However, when the space on the roof is limited, the architect is forced to give it a chance. Architect 27 brought up another reason for mounting the PV on the façade: "We believe that the façade should not only be utilized as thermal insulation for the building, but also to generate energy and communicate and interact with the city and environment". In addition, the client's desire to advertise a sustainable building was also noted.

To sum up, the choice to put PV on the roof, hidden from the visitors' views, seems to be popular response from the architects without experience. It gives less responsibility to the designer and allows the system to be independent and separable.

C. Energy yield vs. design

As explained earlier, in order to use PV in design, on several occasions, architects needed to make a compromise between the functional performance of the PV modules and their design concept. The following section presents the architects' view on this issue. Few of them mentioned that making compromises and adapting are a part of the responsibilities of the architect and, since they were used to it, found it easy to do so.

Some others believed that if PV was considered from the beginning of the design process, there would be no need to adapt the design later.

To conclude, making a balance between the energy yield and aesthetical values in a project is directly linked to investment and payback period of the system. Indeed, this issue seems to be a one of biggest bottlenecks of using PV technology in architecture.

D. Visibility of PV in design

In another part, the respondents were asked about the visibility of PV in the design concept. Similar to the first group with experience, the second group gave a range of varying feedback.

Some architects responded that it depended on the design concept itself, whether or not the photovoltaic cells were to be visible. They believed that when the design is strong enough, and panels are a part of the design, it is fine to have the PV visible as a seamless building service. Some of these architects believed that visibility of the PV system is important because it is a new technology and that the building should achieve a unique look using it. It could be the case that the client and project owners want the PV to be seen, as they have monetarily invested in it and wish to show it off and use it for external communication.

Some others were in favor of hiding PV in the design concept. They argued that, especially on listed buildings or in the intercity refurbishment projects where municipal restrictions apply, PV changes the appearance of the building, and so, it should not be visible. For these projects, there is an apparent demand for the development of PV products that resemble or replicate conventional building materials.

Indeed, the feedback received verified that the opinion of architects on the visibility of PV is diverse, and that it is difficult to make a clear statement on their preferences. However, it can be concluded that if the PV product is tangled as part of the design concept, there are fewer concerns with the visibility of the system.

3.2.3. Expectations of PV Products

In the following part, results regarding the interviewees' expectations of PV products are presented. The majority of respondents spoke more on the physical characteristics of the modules and less so on the technical performance. Architect 16 mentioned that "Current PV is modern and developed from a technical perspective, but it would be good if developers take the product's beauty into account". The majority also mentioned that, in order to use PV in the building, customizability of the product is essential. Several architects complained about the physical limitations of current PV modules, considering it a challenge to include them in the design. However, a majority of these architects were not aware of new technological developments within PV manufacturing. This indicates a large gap between science and market. Others who were aware of recent advancements mentioned that these developments increase the overall cost of the PV system and make it less appealing for investors.

To conclude, it is clear that for projects where the architect is faced with a limited budget, a stock-standard PV product is required that can be ordered off-the-shelf. In projects where architects are less burdened with spending restrictions, however, they would enjoy the choice of being able to utilize custom-built modules, tailor-made to suit the project at hand. The industry should seek to develop and manufacture standard PV modules that come in a diverse range of sizes and colors that make it easier for architects to utilize them in their designs with limited budgets.

3.3. Understanding of Integration

In the context of using PV technology in the building, there is an emphasis on the integration of PV technology. The term BIPV (building-integrated photovoltaics) is used in the field of application of photovoltaic technology in buildings. Since integrated is an important issue that has a high impact on building design: what does integration mean to designers and what kind of applications can be considered? There are several definitions outlined by scientists and practitioners, which have been reviewed by Haghighi et al. (2020). In this portion, the architects, as stakeholders leading in the design process, were asked to express their understanding of the subject.

The results have been analyzed and are presented in Table 3.

Table 3. Understanding of integration.

Understanding of Integration		
Topics	**Description**	**Relevant Quotes**
Verbal definition of Integration	PV being a true element in the design concept in contrast to it being merely an add-on element	• Architect 29: "PV is integrated when it looks like it belongs to the building and is designed in a way that is not just something that is added to the building design." • Architect 14: "To integrate is an aesthetic acknowledgement. At the same time, the actual technical component (the PV), that is either hidden or exposed, is something that is brought into the traditional ways of architectural thinking. Once you accept this, you can't refer to it as integration; you could consider it a part of the overall possibilities of the materials you possess."
	PV product should serve additional functions in the building, other than energy production, in order to be considered integrated	• Architect 11: "PV has to serve some architectural function in addition to its energy generation function—a rain screen module, for example." • Architect 16: "Why not have PV panels that are structurally sound enough that they become part of the structure itself? They should be incorporated in a way that the architecture itself is renewed by the new possibilities. It should be noted, however, that the architecture should not become a slave to these new possibilities (PV technology)."
	PV should be treated as another building material and not expect it to take over functions	• Architect 20: "PV should be treated as just another building material, like a brick that is only a brick or a window that is only a window. PV can be part of the assembly of the building".

	Integration of photovoltaics could only be achieved if we implement an integrated design process and involve all the parties involved from the early stages	• Architect 9: " Integrated design process and integrated product design and integrated manufacturing all addressing the fact that all parties should work together from scratch to reach an integrated outcome."
	Integration as a range of possibilities and diverse meaning depending on architectural style, project, local condition, and design concept	• Architect 30: "When we talk about bricks, we only talk about bricks. You may get some that are handmade and are so nice and fantastic, and then you can get ugly ones that come from factories, which are completely dead in the structure. That's the range of it, but we still call it a brick and I think that with photovoltaics, we should just call it photovoltaics, knowing that there is a range of products that you can use and like." • Architect 4: "Integration is such a broad concept. It has many meanings and has to be defined by the architect in his own architecture; sometimes PV is more pronounced, sometimes less. Sometimes it's visible, and sometimes it's hidden. So, this is not a choice, it's about a response to an idea, the idea of a project, and it's always going to be different."
	Against integration in the meaning of unification of PV with design	• Architect 6: "Having nice architecture is important, but PV should be made a separate element because PV has to be replaced in 15–20 years. If it serves other functions, it will cause many problems for the building."
Visual examples of integration	• Case 1: where state-of-the-art colored PV modules were used where the PV cells are nearly invisible and had been used as a cladding product. The architect had also tilted each of the colored modules to create a pattern on the façade. • Case 2: where standard PV modules are used but made a specific shape out of this module, akin to the scales of a fish	

For the majority (more than 70%) of the architects interviewed, the word "integration" can be defined as "PV being a true element in the design concept in contrast to it being merely an add-on element".

In addition, roughly half (around 50%) of the interviewees stated that the PV product should serve additional functions in the building, other than energy production, in order to be considered integrated. On the other side of promultifunctionality, there were opposing opinions with interviewees, who suggested PV be treated as normal monofunctional element, like other building services or materials.

Another opinion received from two architects was the belief that the integration of photovoltaics could only be achieved if we implement an integrated design process and involve all the parties involved from the early stages of a project. A few other architects described integration as a range of possibilities, depending on the projects, local conditions, and design concept.

One architect, however, was against the idea of integration. He believed integration is not necessary because PV needs to be replaced and changed earlier than the end of life of a building and, therefore, should not be unified with it.

As presented, the ideas and opinions of what integration means to the architects were quite diverse and covered a wide range of stances. It can be said, however, that the majority of architects, whether directly or indirectly, believe that PV should be a part of the design concept. In order to understand the visual implication of given definitions and determining what can be considered "part of the design concept", we showed pictures of realized projects to the interviewees. We believe the visual implication of integration is a quality that cannot be measured in an objective capacity, varying wildly from person to person and from project to project. Therefore, the research team reflects this by not presenting the result of the qualitative assessment: which of the presented projects had received the most votes in terms of integration by the interviewees. Instead, we asked them to explain why they consider it integrated or nonintegrated.

In the responses received, despite subjective opinion on the projects, the majority of the interviewees referred to the same two cases as the example of integration.

One was a project where state-of-the-art colored PV modules were used, where the PV cells are nearly invisible and had been used as a cladding product. The architect had also tilted each of the colored modules as to create a pattern on the façade.

The second project took a different approach. The architect had used standard PV modules but made a specific shape out of this module, akin to the scales of a fish. In contrast to the first project, the PV modules are visible, and the architects could easily spot the modules.

Considering the results presented, the following conclusion can be made: integrated usage of a PV product in a project does not necessarily require design flexibility in the product itself. In other words, integration takes into account the design concept as a whole: it is not necessarily dependent on aspects of the PV product itself, such as the range of customizability, but rather the creativity and innovativeness of an architect and their ability to implement PV products properly into a project.

3.4. Decision-Making Factors

This section presents the results from the quantitative assessment of the important factors in the decision-making process for utilizing PV in buildings. The interviewees were asked to answer on a scale ranging from 0 to 9 to each of the factors listed, based on their importance and on the impact of the decision to implement PV in a given project. Figure 3 presents the average score among all 30 interviewees, ordered from most to least significant:

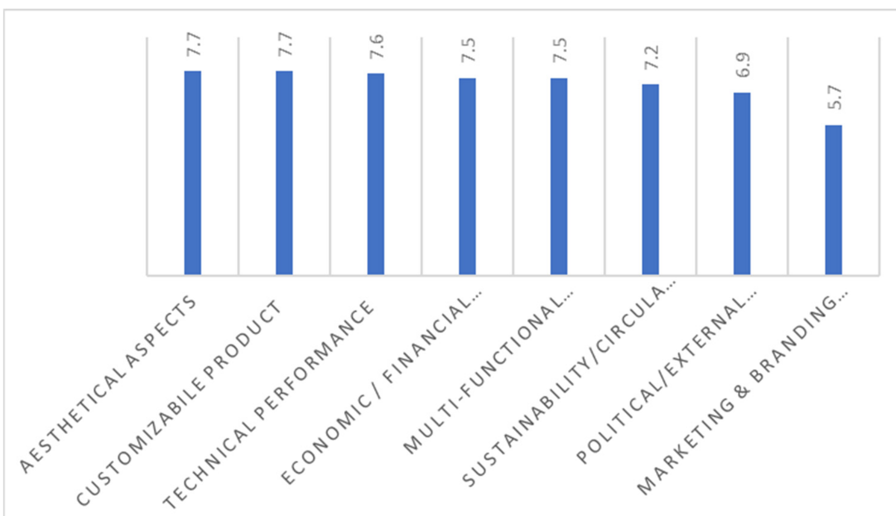


Figure 3. Decision-making factors.

The figure illustrates that several factors strongly influence the decision-making process when working with PV. Although most of the scores are relatively close to each other, it can be seen that design and aesthetic aspects of the product and customizability regarding different physical aspects (e.g., shape, color, size,) are scoring higher than other factors. In terms of significance, the technical performance of the product and financial investment needed are next. Interestingly, marketing and branding of the PV module scored as the least important aspect by the architects interviewed. It is important to note, however, that a few of the architects consider the branching of companies such as Tesla into the photovoltaic market has had a noticeable impact on the acceptability of the technology.

4. Conclusions

The study presented in this paper investigated the input from architects in regards to various aspects of architectural photovoltaic applications (APA). Some of this input is coming from the architects' experience with realized projects and some concern their opinions, perceptions, and other experiences. We utilized the mixed method in this study, which showed to be a useful approach in collecting input in the form of both qualitative and quantitative data.

The main results can be summarized by the following points:

- In regards to PV and architectural design, there is a direct link between the time when PV is introduced to the design concept, the suitable PV product, and the surface used for the application of PV.
- Comparing the experiences of Group A (architects that had applied PV already) and the insight and perceptions of Group B (architects and other designers that had not) showed that working with PV technology in practice was not as difficult and complicated as Group B had expressed. It should be noted that the majority of these realized projects are larger-scale projects and had the background context and budget necessary for the experimentation with PV. Therefore, Group B's insights are still of value and relevant to architects who have yet to utilize this technology in their architectural designs.
- The findings highlighted several practical considerations for APA that need to be taken into account within the design concept:
    - Space required for ventilation and cables of modules
    - Overshadowing of the modules
    - Window-to-wall ratio, size of building openings
    - Accessibility of the system for maintenance and cleaning of modules
    - Safety considerations with PV modules and the supporting structure
    - Weather tightness of the PV system
- This research concludes that versatility in color, transparency, size, and reflectivity of module products are the most requested options by architects. The industry should seek to develop and manufacture standard PV modules that come in a diverse range of sizes and colors, which make it easier for architects to utilize them in their designs.
- Regarding the understanding of architects on the concept of "integration", we learned that architects are interested in seeing PV as part of the design concept itself. It is treated as the most important concern. Assessing this quality, however, is mainly subjective and left to the discretion of the architect. It can be concluded that beside functional integration, having PV serves secondary functions in the building, and architectural integration, assimilating PV into the design concept, are aspects that can be important in determining the scope of integration.

As a reflection, it should be noted that the method applied in this research entails a time-consuming process, from the design and validation of the questionnaire, via the selection of architects and arrangement of interviews, to the transcription and analysis of data. Nevertheless, it remains the best suited approach, which can provide a comprehensive view of the topic for different stakeholders of the subject area.

As a recommendation for future studies, it would be enlightening to see an in-depth analysis of the role that stakeholders and other bodies play in the widespread adoption of PV technology in buildings.

Author Contributions: Conceptualization: Z.H., T.K. (Thaleia Konstantinou), A.v.d.D., and T.K. (Tillmann Klein); methodology: Z.H., T.K. (Thaleia Konstantinou), A.v.d.D., and T.K. (Tillmann Klein); formal analysis: Z.H., M.A.D., T.K. (Thaleia Konstantinou), and A.v.d.D.; investigation: Z.H. and M.A.D.; data curation: Z.H.; writing—original draft preparation: Z.H. and M.A.D.; writing—review and editing: Z.H., T.K. (Thaleia Konstantinou), and A.v.d.D.; supervision: T.K. (Thaleia Konstantinou), A.v.d.D., and T.K. (Tillmann Klein); project administration: A.v.d.D.; funding acquisition: A.v.d.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was part of the SolarUrban Research Programme, funded by TU Delft.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Human Research Ethics Committee (HREC) of TU Delft on 3 April 2019.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available since it belongs to the research group and is part of ongoing research.

Acknowledgments: The research team would like to express their gratitude to the architects who participated in this study and to our other colleagues for their help and support in arranging the interviews. We would not be able to involve such prominent interviewees in our research without their help. In these terms, special thanks to Professor Thijs Asselbergs. Moreover, special thanks to Soheil Nouri with his assistance with the manual transcription of the interviews.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Questionnaire Type A

Appendix A.1. Experiences & Lessons Learnt

1. When and by whom the idea of PV came up within this project?

Appendix A.2. Pre-Design (Decision-Making Process)

2. What were the main driving force and barrier to the idea of using PV in the project?
3. What was the role of the different stakeholders in the decision-making process?
4. Were they any urge of using specific PV product/type? (any technology or integrated)
5. Was PV part of the design concept of the project? Or was an add-on to final design?
6. Were there clear preferences to have PVs visible/invisible in the project?
7. How did you find this product? What channels did you use to find PV product?
8. To what extent the Design adapted to physical characteristics of PV product? What aspects have been imposed? Was it your call or market decision?
9. If you were involved in the product development of this product, what would you change/improve?
10. Could there be an alternative way to design with PV in this project?
11. Could there be an alternative fabric to use for PV? (e.g., façade/roof?)
12. What were the challenges/difficulties during construction process working with the PV product?
13. How does the owner feel about the experiences of using PV in the project?
14. Overall what are the lessons learnt from using PV in this project?
15. Considering all the issues/experiences (a) would you use PV again in this project? (b) What are do and don't as takeaways?

Appendix A.3. Understanding of Integration

16. In general, do you think the term "integrated PV" is appropriate for the use of PV in the building?
17. What would you define it in this context?
18. Looking at the pictures (is printed in large format) of different typologies for the use of PV in buildings,

19. Which can be closer to your definition of integration?
20. Which one do you think is a better approach? Or all are fine?

Appendix A.4. Decision-Making Factors

21. To what extend below aspects can be decisive during the decision making the process for choosing PV product? Scale 1–9 Please consider that some of their values are in contrast with each other.
    - Economic/Financial aspects (e.g., payback period, initial investment, business plan)
    - Political/external incentives (e.g., feed-in-tariff, nZEB, sustainability certificates)
    - Technical performance (e.g., efficiency, shade resilience, durability)
    - Multi-functionality (e.g., shading devices, fenestration, rain screen)
    - Aesthetical aspects (e.g., form, homogeneity)
    - Customizability (e.g., size, shape, pattern)
    - Sustainability/circularity aspects (e.g., recyclability, embodied energy)
    - Marketing and branding aspects (e.g., Tesla campaign for tesla roof)
    - Other?

Appendix B. Questionnaire Type B

Appendix B.1. Insights and Perceptions

1. Please select one of your projects in your mind and please mention, would you include one of these PV products in the project?

If yes:

2. Considering the same Architectural design, wherein this project would you use PV?
3. How would this decision influence other aspects of your design?
4. Who (from the different stakeholders) do you think would be against this decision? Why?
5. Could there be an alternative way to design with PV in this project? Could there be an alternative fabric to use for PV? (e.g., façade/roof?)
6. What challenges/difficulties would you envision during construction process working with a PV product?
7. Considering all the mentioned issues/problems resolved, would you use PV in your next project?

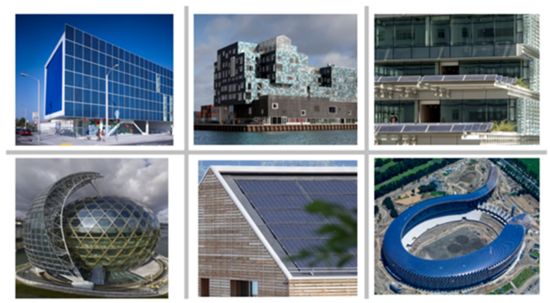
If no: Why?

8. It is because products are not meeting your expectation? What are your expectations?
9. Don't you find the use of PV in buildings interesting?
10. What can make PV interesting? Multi-functionality? Different Business Plan?

11. Are they expensive? Or what else?
12. In what situation would you consider using? What could drive you to such a decision?
13. Who (from the different stakeholders) do you think would be against this decision? Why?
14. Considering all the mentioned issues/problems resolved, would you use PV in your next project?

Appendix B.2. Understanding of Integration

15. In general, do you think the term "integrated PV" is appropriate for the use of PV in the building?
16. What would you define it in this context?
17. Looking at the pictures (will be printed in large format) of different typologies for the use of PV in buildings,



18. Which can be closer to your definition of integration?
19. Which one do you think is a better approach? Or all are fine?

Appendix B.3. Decision-Making Factors

20. To what extend below aspects can be decisive during the decision making the process for choosing PV product? Scale 1–9 Please consider that some of their values are in contrast with each other.
    - Economic / Financial aspects (e.g., payback period, initial investment, business plan)
    - Political/external incentives (e.g., feed-in-tariff, nZEB, sustainability certificates)
    - Technical performance (e.g., efficiency, shade resilience, durability)
    - Multi-functionality (e.g., shading devices, fenestration, rain screen)
    - Aesthetical aspects (e.g., form, homogeneity)
    - Customizability (e.g., size, shape, pattern)
    - Sustainability/circularity aspects (e.g., recyclability, embodied energy)
    - Marketing and branding aspects (e.g., Tesla campaign for tesla roof)
    - Other?

Appendix C. List of Interviewees

Group A: Architects with Realized PV Projects				Group B: Other Parties		
No	Architecture Firm	Interviewee	Project	No	Architecture Firm	Interviewee
1	NBA Architect	Harold van de Ven	De Willem en de Zwijger	16	Dutch Government Architect	Floris Alkemade
2	Sunsoak	Jean-Didier Steenackers	Bota Solar	17	Architekturbüro Hagemann	Ingo Hagemann
3	Mario Cucinella Architects	Mario Cucinella	Sino-Italian	18	Van Schagen	Arjan Gooijer
4	Renzo Piano Building Workshop	Bernard Plattner	Paris Courthouse	19	Felixx Landscape Architect	Marnix Vink
5	Renzo Piano Building Workshop	Giorgio Bianchi	Stavros Niarchos Foundation	20	EOC Engineers	James O'Callaghan

6	Broekbakema	Steven Schulze	Energy Academy	21	Octatube	Mick Eekhout
7	SGP Architects	Simone Giostra	GREENPIX,	22	KAAN Architecten	Kees Kaan
8	Mecanoo	Dick van Gameren	De Spakler	23	Marjan van Aubel	Marjan van Aubel
9	OZ Architects	Wouter Zaaijer	Breeze Hotel	24	MVRDV	Nathalie de Vries
10	Dam Architect	Diederik Dam	European Patent Office (EPO)	25	Haskoning Architects	Sven Spierings
11	Kiss and Cathcart	Greg Kiss	APS Fairfield PV	26	Braaksma & Roos	Job Roos
12	Foster + Partner	Paul Kalkhoven	HQ in California	27	Solarix Studio	Marloes van Heteren
13	Van den Berg	Dick van de Merwe	Hoornbeeck College	28	Superuse Studios	Jos de Krieger
14	C.F. Moller	Mads Mandrup Hansen	Copenhagen School	29	Bear-id	Tjerk Reijenga
15	UNStudio	Ger Gijzen	Hanwa HQ	30	Arup Architecture	Nille Juul-Sorensen

References

1. SIST. Standard EN 50583:2016; *Photovoltaics in Buildings BIPV Modules*; SIST: Ljubljana, Slovenia, 2016; pp. 1–22.
2. Scognamiglio, A.; Røstvik, H.N. Photovoltaics and zero energy buildings: A new opportunity and challenge for design. *Prog. Photovoltaics Res. Appl.* **2012**, *21*, 1319–1336, doi:10.1002/pip.2286.
3. Van Veen, L. The "New" Zero Energy Office Building: The Impact of Dutch Regulatory Changes on the Development of Energy Efficient Office Buildings. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2020.
4. EUR-Lex-02010L0031-20181224. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583922805643&uri=CELEX:02010L0031-20181224 (accessed on 20 January 2021).
5. Hagemann, I.; Architektur, D.I. The Integration of Photovoltaics in Buildings—Design Considerations and Examples of Buildings. *Photovoltaics* **1996**, *4*, 26–29.
6. Saretta, E.; Bonomo, P.; Frontini, F. Active BIPV Glass Facades: Current Trends of Innovation. In Proceedings of the GPD Glass Performance Days, Tampere, Finland, 28–30 June 2017.
7. Bonomo, P.; Zanetti, I.; Frontini, F.; van den Donker, M.N. BIPV Products Overview For Solar Building Skin. In Proceedings of the 33rd European Photovoltaic Solar Energy Conference and Exhibition BIPV, Amsterdam, The Netherlands, 25–29 September 2017; pp. 35–40.
8. *BIPV Market and Stakeholder Analysis and Needs*; Project Report: R2M, Onyx Solar, Flisom, BEAR-iD, Acciona; EU: Brussels, Belgium, 2016; p. 52.
9. Prieto, A.; Klein, T.; Knaack, U.; Auer, T. Main perceived barriers for the development of building service integrated facades: Results from an exploratory expert survey. *J. Build. Eng.* 2017, *13*, 96–106, doi:10.1016/j.jobe.2017.07.008.
10. Larsson, D.; Benson, J.; Woess-Gallasch, S.; Frederiksen, K.; Hendrick, P.; Frieden, D. *Transition towards Sound BIPV Business Models—Inventory on Existing Business Models, Opportunities and Issues for BIPV IEA PVPS Task 15 Subtask B-Transition towards Sound BIPV Business Models*; IEA-PVPS: Brussels, Belgium, 2018; ISBN 978-3-906042-70-1.
11. Farkas, K.; Munari-Probst, M.C.; Horvat, M. Barriers and Needs for Building Integration of Solar Thermal and Photovoltaics. *Proc. EuroSun Conf.* 2010, doi:10.18086/eurosun.2010.12.05.
12. Lucchi, E.; Lopez, C.S.P.; Franco, G. A conceptual framework on the integration of solar energy systems in heritage sites and buildings. In *Proceedings of the IOP Conference Series: Materials Science and Engineering*; IOP Publishing, Bristol, UK, 2020; Volume 949, p. 12113.
13. López, P. Acceptance of Building Integrated Photovoltaic (BIPV) in Heritage Buildings and Landscapes: Potentials, Barrier and Assessment Criteria. In Proceedings of the Construction Pathology, Rehabilitation Technology and Heritage Management, Granada, Spain, 24–27 March 2020.
14. Horvat, M.; Dubois, M.-C.; Snow, M.; Wall, M.; Amado, M.; Bouffard, É.; Ehrbar Hochschule Luzern, D.; Shirley Gagnon, S.; Hagen, R.; Kanters, J.; et al. International Survey about Digital Tools Used by Architects for Solar Design. In *Task 41—Solar Energy and Architecture, Subtask B-Methods and Tools for Solar Design*; IEA SHCP: Rapperswil-Jona, Switzerland, 2011.
15. Farkas, K. The Art of Photovoltaics. *Proc. ISES Solar World Congr.* 2011, *3*, 2052–2063, doi:10.18086/swc.2011.17.09.
16. Attia, S.; Bilir, S.; Safy, T.; Struck, C.; Loonen, R.; Goia, F. Current Trends and Future Challenges in the Performance Assessment of Adaptive Façade Systems. *Energy Build.* **2018**, *179*, 165–182, doi:10.1016/j.enbuild.2018.09.017.
17. Yin, R. *Case Study Research: Design and Methods*, 4th ed.; Sage Publications: Thousand Oaks, CA, USA, 2009; ISBN 9781412960991.
18. Lavrakas, P. *Encyclopedia of Survey Research Methods*; Sage Publications, Inc.: Thousand Oaks, CA, USA, 2012;.
19. Creswell, J.W. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*; Sage Publications: Thousand Oaks, CA, USA, 2009; ISBN 978-1-4129-6557-6.
20. Euroconstruct. Constrcuction Market Reports. Available online: https://www.euroconstruct.org/ec/reports (accessed on 27 August 2020).
21. Kuhn, T.E.; Erban, C.; Heinrich, M.; Eisenlohr, J.; Ensslen, F.; Neuhaus, D.H. Review of Technological Design Options for Building Integrated Photovoltaics (BIPV). *Energy Build.* **2020**, 110381, doi:10.1016/j.enbuild.2020.110381.