

Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences



Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information		
Name	Bo Valkenburg	
Student number	4713168	

Studio		
Name / Theme	Fire safety BIPV	
Main mentor	Arie Bergsma	Façade & Product Design
Second mentor	Siebe Broersma	Climate Design & Sustainability
Argumentation of choice of the studio	Fire safety is a critical aspect within the built environment, directly influencing the well-being of occupants and the resilience of buildings against potential disasters. While the subject is relevant across all studios of Building Technology, it is underemphasized as a topic within the faculty of Architecture. Consequently, a decision was made to focus on a fire-related topic related to an emerging sustainable technology within façade & climate design: building integrated photovoltaics. This choice aims to underscore the importance of fire safety, especially within the context of emerging technologies that lack proper norms and guidelines.	

Graduation project	
Title of the graduation project	Fire safety of Building Integrated Photovoltaics (BIPV): a risk-based design framework for designing with BIPV
Goal	
Location:	Delft university of technology
The posed problem,	Fire hazards related to buildings are mitigated by fire safety regulations and standards, offering guidelines on implementing measures to minimize the loss of human life and property damage (Kodur et al., 2019). The prescribed design strategies and evaluation methods vary based on the building's function and fire safety standards and regulations. Traditional standards and regulations were primarily designed for buildings with conventional components, leading to a lack of specific fire safety guidelines for "green" technologies (Meacham & McNamee, 2020). BIPV systems are recognized as critical "green" building components as they provide both building functional and electro-technical attributes, thereby falling under two distinct

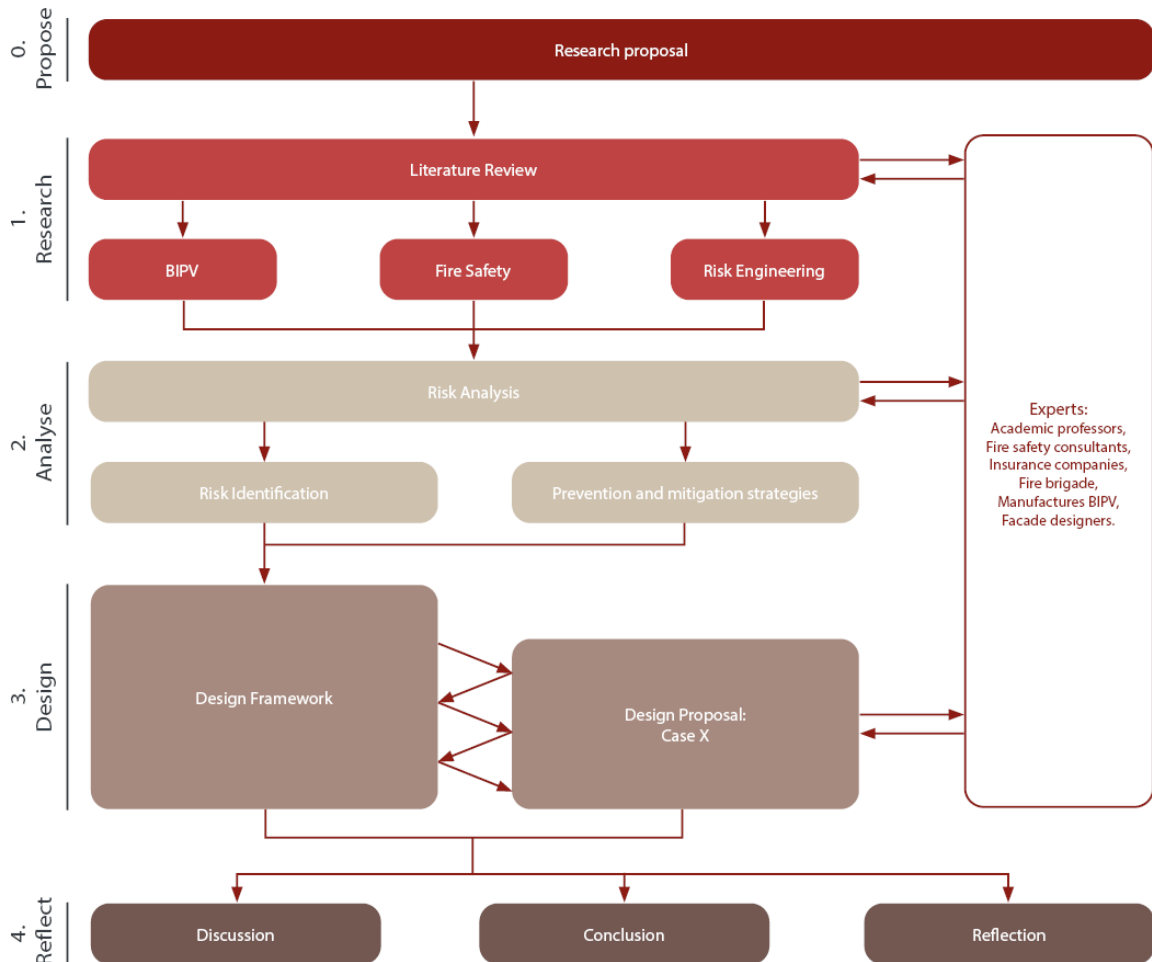
fire safety domains: electricity production components and building components (Bonomo et al., 2018). In contrast to the characteristics of conventional building components, the BIPV systems provide new fire hazards to buildings, such as providing a fire ignition source, increasing fire propagation, impact occupancy evacuations and impact fire department and rescue response (Yang et al., 2023). Therefore, there is a need to properly prevent and mitigate the fire hazards when employing a BIPV system in buildings.

Despite the relatively high criticality of BIPV systems, the existing fire safety codes and standards lack comprehensive provisions for their diverse applications, posing challenges to ensuring their fire safety verification (Aram et al., 2021). Conforming to the requirements outlined in current building codes, regulations, and standard test methods does not adequately address the unique considerations associated with BIPV systems. TNO (2019) investigated fire incidents with BIPV systems in the Netherlands and identified in-roof BIPV systems as posing the highest fire safety risks for buildings. This arises from the absence of specific requirements in the Dutch Building Code regarding the combustibility of materials situated directly behind the outer layer—in this case, the PV panel. Unlike on-roof BAPV systems, where panels are always placed on top of incombustible roof tiles, in-roof BIPV systems lack this protective layer. To address this gap, Aram et al. (2021) argue that achieving comprehensive fire safety provision demands further research into the specific impact of PV fires on overall building fire safety. Notably, current studies predominantly concentrate on examining performance failures and faults of PV cells, neglecting the broader context of PV systems in buildings. This underscores the pressing need for a more integrated approach to fire safety that covers the evolving landscape of “green” building technologies like BIPV systems (Meacham & McNamee, 2020).

Emphasizing the importance of integrating fire safety considerations at the beginning of the design process for emerging technologies, rather than treating it as an afterthought, Meacham & McNamee (2020) highlight that mitigation costs are invariably higher when addressed towards the end of the process as opposed to the initial stages. This highlights the necessity for an integrated approach to fire safety in the early stages of designing with BIPV.

	There is currently limited literature available about addressing the fire hazards and risk associated with BIPV systems and how to prevent and mitigate them properly. Existing research on BIPV systems predominantly centers around performance and feasibility, with limited or no mentions of their fire safety aspects. This disparity is somewhat concerning, considering that the fire safety of a product influences its overall feasibility and should be a crucial aspect of any comprehensive analysis. Therefore, it is essential for the BIPV industry to raise awareness, acknowledge and to address these hazards appropriately. While available literature on the fire safety of BIPV systems often addresses singular or multiple fire risks, proposing prevention and mitigation strategies, it seldom links these risks to specific BIPV systems and design considerations within a building context. Considering the pre-normative phase of BIPV fire safety (Yang et al., 2022), there is a need for comprehensive guidance to help designers efficiently integrate strategies, ensuring maximum fire safety within diverse building contexts and enabling a more tailored and effective approach in the absence of standardized regulations. With BIPV systems introducing new fire hazards to buildings, it is crucial to conduct comprehensive research and establish guidelines to address their impact on building safety. This underscores the necessity for an integrated approach to fire safety during the early stages of the design process.
research questions and	Research question: How can a risk-based design framework support facade designers in the early stages of the design process to achieve fire-resilient designs when integrating building integrated photovoltaic systems? Sub research questions 1. What are building integrated photovoltaics and their characteristics related to fire? 2. How is fire safety managed in buildings in the Netherlands? 3. How is fire safety managed in relevant electric products, like cars? 4. How is the fire safety of building integrated photovoltaics managed? 5. How can classical risk theories contribute to the identification and documentation of fire risks

	associated with building integrated photovoltaic systems? 6. What fire hazards and associated risks are linked to building-integrated photovoltaics? 7. How can fire hazards and associated risks linked to building-integrated photovoltaics be effectively prevented or mitigated? 8. How can the preventive and mitigative measures be translated into a comprehensive design framework that aids facade designers in the early stages of the design process?
design assignment in which these result.	This thesis will result in a design framework that support façade designers in the initial stages of their projects to achieve fire-resilient designs when integrating building integrated photovoltaic (BIPV) systems. This framework will be developed by the systematic identification and assessment of risks associated with BIPV systems, followed by the proposal of targeted mitigation strategies tailored to the specific design choices made. The risk assessment will be executed in collaboration with experts related to BIPV and fire safety. By providing a structured guidance tool, the design framework will offer essential considerations for mitigation and prevention based on chosen systems, addressing potential impacts on fire safety on a building level. To validate the effectiveness of the design framework, a design proposal will be implemented utilizing its guidelines. The documented impact of the design framework on the choices made during the design process will serve as feedback to refine and enhance the framework.
Process	
Method description	



0. Preliminary Proposal

Preliminary research will be conducted in order to find the academic gaps within the topic of fire safety of BIPV. This knowledge will then be utilized to propose the first concept of the graduation plan, consisting of: problem statement, research objective and research questions.

1. Literature Review

The literature review will consist of thorough research on three main topics to get a grasp on the knowledge required to achieve proper understanding of the relatively unknown fields of work (for me). These three topics are: BIPV, fire safety and risk engineering. The information required will be retrieved by systematically reviewing and documenting papers and by consulting external experts. The papers will be found by using relevant keywords in search engines such as Scopus, Web of Science and Google Scholar. Subsequently, a software called Zotero will be utilized to categorize all the papers and to systematically take notes.

2. Risk Analysis

The knowledge gained from the literature will be used to execute a qualitative what-if risk analysis on the fire safety of BIPV. Initially, a setup will be devised, drawing from the identified fire risks associated with BIPV in the literature. Simultaneously, an initial framework will be established for preventive and mitigative measures and strategies. In the subsequent step, collaborative brainstorming sessions will be held with experts from diverse professional backgrounds, fostering in-depth discussions and diverse

perspectives. The outcomes of these sessions will be integrated into the what-if analysis to finalize the assessment.

3. Research by Design

The prevention and mitigation strategies found by the risk analysis will be translated to a design framework which aids façade designers in the initial stages of their projects to achieve fire-resilient designs when integrating BIPV systems. This will be created by categorizing and prioritizing the strategies based on their effectiveness and adaptability. The design framework should offer essential considerations for mitigation and prevention based on chosen systems, addressing potential impacts on fire safety on a building level.

Subsequently, an iterative process will begin, involving the creation of a BIPV-integrated facade design guided by the developed framework. This design proposal will not only serve as a practical application of the framework's principles but also as a means to validate its effectiveness. The documented impact on decision-making during the design process will provide valuable feedback, enabling refinements and enhancements to the framework for improved practicality and applicability.

Additionally, input from experts in BIPV and fire safety will be incorporated to ensure the framework is easy to use and serves its purpose.

4. Reflection

As a final step, a discussion, conclusion and reflection will be done on the entire process of this master thesis. This will highlight the most important findings, articulate the significance of the study and offer insights to potential future research directions.

Literature and general practical references

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The topic of "Assessing the fire safety of Building Integrated Photovoltaics (BIPV): a risk-based design framework for designing with BIPV" addresses fire safety as a topic which impacts two Building Technology chairs: Façade & Product Design and Climate Design & Sustainability. While fire safety is typically viewed as a validation measure within these chairs, the research seeks to reposition it as an integral component, acknowledging its significance in shaping resilient and sustainable building designs. BIPV systems hold great promise in its contribution to a sustainable built environment and thus serves as an ideal case study.

Additionally, the established field of work of risk engineering will be utilized within this graduation topic, as this discipline offers a systematic and analytical approach to evaluate potential hazards and vulnerabilities. Risk engineering has proven its value and effectiveness in other industries, but within the realm of Building Technology this discipline lacks proper integration.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

The global verdict on reducing energy demand has urged the built environment to employ "green" technologies which are clean and energy efficient (Meacham & McNamee, 2020). As energy consumption within buildings is projected to be rising, the imperative to generate on-site energy becomes increasingly vital to relieve the strain on resources. On-site BAPV systems have already proven to be highly effective in generating energy, but also come with inherent disadvantages which limit the implementation possibilities and efficiency. BIPV systems have risen as a technological solution designed to address these limitations of on-site BAPV and off-site PV systems, and provide advantages such as: enhanced aesthetics, utilization flexibility, provide building functionalities, reduce need for PV plants, minimize energy transmission losses.

According to IEA PVPS Task 7 (2002), BIPV in the Netherlands had a potential to produce 31.887 TWh/year on all building façades and roofs, which at the time would take account for 32.2% of the actual energy consumption of buildings (99.06 TWh/year). While more recent and comprehensive studies on BIPV system potential are currently unavailable, it's important to acknowledge that the actual potential will be lower due to increased energy consumption since 2002. Nevertheless, these earlier statistics emphasize the significant potential of BIPV in reducing the overall energy demand of buildings.

However, as more BIPV systems are being installed in the Netherlands, also more cases of fires caused by these systems are being reported. TNO (2019) investigated that in 2018 there were 23 PV related fire accidents in residential buildings out of

170.000 systems placed on residential buildings. While this number may seem relatively low, it is important to note that it is an underrepresentation due to the lack of clarity on the actual cause of fires in many cases or the unavailability of data due to ongoing investigations by authorities. Aram et al., (2021) reports that in Germany between 2011 and 2013, there were 430 reported fire incidents among 1.3 million installed PV systems, with 50% directly caused by the PV systems themselves. Cancelliere (2016) underscores an investigation conducted by the Italian National Firefighters Brigade, revealing that out of 590,000 installed PV systems, 1,600 fires were associated with these systems. Although it is unclear in these reports if the fire cases involved BIPV or BAPV systems, they do signify the concern regarding the safety implications of increased PV system deployment.

Preliminary literature list

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Personal planning

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