A method for human-centered appraisal of façade design for serviceability

Graduation Thesis Reflection

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1 Reflection

1.1 Graduation Process

1.1.1 How is the graduation topic positioned in the studio?

Building facades face a unique challenge in the future – striking a balance between global sustainability challenges such as climate change, material scarcity, energy poverty etc. and trying to meet the high standards of human comfort. The Facades and Products graduation studio focuses its research on developing novel solutions to face this challenge. As much as there is need to focus research on new materials and new technologies, there is also an urgent need to critically analyze the conventional. This graduation topic is appropriately positioned in the studio as it questions the current serviceability norms that govern, and at times, justify the specification of glass thickness in facades. A critical analysis is crucial to understand whether a balance between material efficiency in glass and human acceptance of glass deformation can be achieved; and if yes, what are the ways to achieve it.

1.1.2 What is the relationship between the methodical line of approach of the graduation studio (related research program of the department) and your chosen method?

Typically, the methodical line of approach of the studio is either research through design or research through experiment. Topics related to novel ideas in facades typically follow the former approach and those related to research on new materials follow the latter. This topic lies at the intersection of both these approaches. Rather than a novel design or novel material, the thesis develops a novel methodology of an experiment to explore potential of material efficiency in a conventional material i.e. glass. The design of the experimental setup follows a research through design approach. The experimental setup itself facilitates research through experiment.

1.1.3 What is the relation between your graduation project topic, your master track and your master program?

Building Technology (BT) curriculum deals with the non-subjective or technical aspects of building design, and is rightly positioned within MSc Architecture, Urbanism and Building Sciences (AUBS). Even though BT curriculum focuses on technical aspects while maintaining a strong relationship with the needs from a user's perspective, it is typically associated with quantitative research. Human acceptance of glass deformations is at the core of this thesis topic. Thus, in addition to quantitative research, there is also a need to conduct qualitative research from the perspective of building occupants. The proposed experimental methodology can be used to measure both objectively and subjectively, the effects of glazing deformation on human comfort. It can also be used to measure acceptance at a larger scale of a street or a neighborhood, which governs the perceived 'value' of the project. This topic is of value to not only facade engineers but also architects and urbanists involved in the decision making process of building façades.

1.1.4 How are the research and the design related? How did your research influence your design/ recommendations and how did the design/ recommendations influence your research?

The words 'research' and 'design' individually have different connotations. While research pertains to academic exploration over a longer period of time in the realm of a broader subject, design pertains to a solution, often for a very specific problem in a given time and context. However, both these terms influence one another. In context of buildings, the design of its components significantly relies on knowledge generated through previous research. Similarly, as the design of components advances to meet the challenges of the future, it opens up new avenues for research.

In the context of this thesis, the decision to design a novel methodology was mainly a product of research. The study of current serviceability norms followed in practice, which was conducted through a literature review and a façade industry survey, highlighted a knowledge gap in terms of occupant acceptance of glazing deformation. Thereafter, specific research into experimental methods was conducted to better define the scope of the proposed experiment. However, as the design progressed, it also prompted more specific research topics related to the mechanisms, their inter-operability, theoretical validation and

potential outcomes. Thus, research at a smaller scale was conducted to answer each of these questions and drive the design process forward. Interestingly, the outcome of this thesis i.e. the experimental setup is to facilitate further research.

While research at a broader scale was the main driving factor behind design of the methodology, the process of design prompted the need for more specific research on smaller sub-topics. For example, since laminated glass panels were not available for the final experiment, it was decided to apply a self adhesive transparent film to ensure safety in case of glass breakage during the experiment. For this, a small experiment to test integrity of a safety film was conducted, to prove that it is fit for use in the final experimental setup. Thus it can be said that while research is an integral part of the design process, the design process prompts the need for further research.

1.1.5 How did the research approach work out & did it lead to the results you aimed for?

Once the research question and sub-questions were defined, it was observed that different sub-questions required different methods of research. Hence, a mixed-method research approach was followed, which involved literature review, façade industry survey and research through design of an experimental setup.

While the literature review about serviceability norms in practice was found insufficient, the combined results of literature review and façade industry survey led to a comprehensive state-of-the-art knowledge about serviceability criteria followed in practice, perceived effects of glazing deformation on its performance and perceived barriers in transitioning towards use of thinner glass for facades. In addition to these expected results, subjective information in the form of opinions and apprehensions was also retrieved. These results were then analyzed qualitatively to infer patterns in the rationale of the responses. One of the main reasons for successful retrieval of results was that the number of responses analyzed (67) was a suitable sample size. In addition, the survey had a combination of numerical and 'free text' questions and some of the questions helped validate information received from the others.

In terms of design of the experiment, the research was a back and forth process. The process involved building of the prototypes, the electro-pneumatic circuit and the design of the stages of the experiment. Since the prototypes were built manually using a hardwood frame and were manually assembled in the workshop with limited expertise, at some instances they gave way to the cavity pressure. The electro-pneumatic circuit required a series of specific connections, some of which were not available, and had to be manually prepared. For instance, the pressure transducer is too large to fit directly in the spacer, so a customized connection was created for this purpose. Further the prototypes do not provide a fair representation of the final panels, so the calibration of the experimental setup could only be done after the final panels were received, which delayed the process. Hence, although the design of the experiment was not a linear process, suitable proof of concept was achieved for creation of the final experimental setup.

1.2 Impact of the graduation project

1.2.1 How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

The project has a substantial academic value since it is not restricted to a single domain of expertise. The project demands a multi-disciplinary understanding of topics including mechanical behavior of glass, factors affecting human perception, fundamentals of electro-pneumatic systems and statistical analysis of retrieved information from the experiments. In addition, the researchers also have to take into account practical concerns such as logistics and time to be spent on prototype building. At an academic level, the project itself benefits from a multidisciplinary design thinking approach.

Serviceability is mainly concerned with the use-case scenario of building elements, governed by human acceptance levels. However, conventional standards ignore an intrinsic characteristic of human acceptance levels – that these are not fixed. This also means that with the right methods, these levels can also be raised or lowered by design. This project not only proposes a methodology to measure these levels, but also compares conditions which have a potential to raise acceptance thresholds. Thus, the project has a significant societal impact, as it fundamentally challenges the norms that consider human acceptance levels as fixed.

The scope of this project is limited to the effect of deformations in façade glazing under wind and climatic loading on occupant acceptance criteria. The occupant acceptance criteria includes 4 themes – perception of safety, satisfaction with the quality of view, disturbance in activity and general acceptance of deformed glass. The project excludes acceptance of deformation from exterior of the façade.

The main implication of the project is the role of prior knowledge among occupants about the material capacity of thinner glass and benefits it offers in terms of saving embodied carbon, on acceptance thresholds. The experiment methodology is flexible and involved many variables. But for the scope of this project, most variables other than prior knowledge have been fixed. The methodology thus can be used to test the implications of other variables in the future, such as variations in indoor environment quality, variations in activity or relative position of the volunteer with respect to the façade. Overall, the project promotes and ethical approach towards design by providing a methodology for participatory design.

1.2.2 To what extent are the results applicable in practice?

Traditionally, influence of dynamic wind loads on building facades is analyzed either using FEM models, or wind tunnel tests on façade prototypes. FEM analysis provides a detailed understanding of mechanical behavior of glass. Wind tunnel tests are quite extensive and require a specialized setup, and are suitable to observe influence of wind loads on glass and other façade components. However, to analyze the impact of deformation on occupant acceptance, these methods are not suitable. The proposed experimental setup is flexible and can be set up not only in a lab, but also at construction sites, or in offices where acceptance analysis can be easily conducted.

To measure the impact of deformations of durability of the sealant, this setup can be utilized for an accelerated durability tests through repetitive movement of the seal. To measure the impact on optical performance, this setup can be installed in a lab or even on the construction site at various heights to observe impacts of deformation from both, inside and outside. Thus the outcome of the thesis is fairly applicable in practice, requiring minor adjustments based on the purpose of the experiment.

1.2.3 To what extent has the projected innovation been achieved?

The lack of a methodology to measure acceptance thresholds towards glazing deformations prompted the proposal of a novel solution. The project was successful in providing a proof of concept for a novel methodology. While the components of the experiment, namely, the method of conducting an experiment with the volunteers, electro-pneumatic systems, data retrieval and analysis techniques themselves are not novel, the combination of these to solve the problem at hand is innovative. Thus, the projected innovation has been achieved to a satisfactory extent in the thesis.

1.2.4 Does the project contribute to sustainable development? What is the impact of your project on sustainability (people, planet, profit/prosperity)?

Material efficiency through optimization (e.g. in steel, concrete, timber) is a common method implemented with the intention of reducing embodied carbon in buildings. The project attempts to pave way for transitioning towards use of thinner glass in facades. Thus, the project contributes towards sustainable development beneficial for our planet by providing a methodology of assessment of thresholds that are conventionally considered high and fixed. As mentioned earlier, the project promotes a participatory design approach towards facades, thus prioritizing people's perception over conventional standards. Reduction of material consumption increases the profitability of the project for the developers, but also reduces the pressure on our resources. Compared to use of recycled glass and reused glass, which are not acceptable in certain projects due to their perceived lower quality, use of thinner glass can be considered to have a relatively higher value.

1.2.5 What is the socio-cultural and ethical impact? What is the relation between the project and the wider social context?

A participatory design approach seems to imbue an ethical dilemma among architects and engineers, wherein stakeholder perspectives have to be considered in combination with their expert propositions. With the methodology proposed in this project, it is envisioned that for a particular project, acceptance of façade

deformations can be tested with the future occupants of the building. From this perspective, the project takes an ethical stand in favor of a participatory design approach.

It has been observed that serviceability limits are non-standard around the world. For instance, the acceptable horizontal displacement of tall buildings under wind/ earthquake loading is different in different countries, and so are the standards limiting these. Acceptance is closely tied with the socio-cultural context. The presence of a methodology to measure acceptance thresholds makes the need for fixed limits redundant. It also attempts to raise acceptance towards efficient facades, by means of educating occupants about the benefits of using thinner glass. Thus, the project has a significant socio-cultural impact and ethical impact with a deep connection with the wider social context.

1.2.6 How does the project affect architecture / the built environment?

By providing a way of transitioning towards 'lean' facades, the project attempts to have a positive impact on the sustainability of the built environment. Additionally, the project questions the traditional way of using glass, conventional perception of glass as a rigid material and unacceptance of deformations in glazing. It proposes that instead of rejecting deformations, the architect should design for inclusion of deformations in glazing. There is a need for a paradigm shift from what has been considered aesthetically appealing towards what pragmatically contributes towards sustainable development. By providing methods for material efficiency in glazing, the project challenges the conventional norms and pushes the architect towards reimagining the use of glass in facades.

1.3 Reflection Questions (self developed)

1.3.1 In what way could you have improved the results of your thesis?

Prototyping and testing the experiment were a major part of development of the methodology. These processes take time and are dependent on factors outside of the direct influence of the researcher. One of the ways to improve the results would be to spend more time on prototyping, with the right materials, having enough buffer time for delivery and testing of components of the experiment and leave enough time towards the end for contingency.

The experiment setup also needs to be validated theoretically, so as to predict behavior of the components and the circuits. For example, the effect of lamination on deformation of a glass pane had to be theoretically verified before ordering the panes for testing. This was performed to a basic level in the thesis, but it can be improved with the use of FE modelling. Further, an in-depth understanding of pneumatics is required to accurately replicate the desired behavior of glass pane under dynamic loading. This would involve the use of data such as pressure variation over time on a façade over a storm condition, translated to equivalent frequency and flow rate controlled by valves in the experiment.

1.3.2 What could be an alternative approach to solve this problem?

A physical setup for the experiment was chosen over a virtual (VR enabled) setup, since a physical setup would provide more accurate reactions from volunteers. Alternatively, the experiment can also be conducted in a fully VR enabled environment or a hybrid setup. The benefit of a VR enabled environment is that a large number of variations in the environment are possible to be tested. Another benefit is that a larger sample size can be tested, since the setup is more flexible and portable compared to a physical setup. In terms of environment, VR can allow us to get results for various orientations and distances from the facade, different levels and modes of deformation, and various building typologies and activities. A hybrid setup is even more suitable, since the VR environment can be used to measure a broad number of scenarios, while the physical setup can be used for benchmarking of real-time thresholds.

1.4 Personal Reflection

1.4.1 How do you assess the value of your way of working (your approach, your used methods, used methodology)?

The well structured format of the graduation studio helped one in following a systematic research and design approach for this thesis. However, the research and design process was intertwined with one another and was not linear. This approach was suitable for this research project, as a novel methodology was being developed. Therefore, it was imperative to conduct an extensive state-of-the-art review (in this case a combination of literature review and industry survey) including relevant research methodology for serviceability of building components like floor slabs and beams. The industry survey and involvement of industry partners helped in anchoring the thesis process in the realm of practice rather than being abstract, which was a personal goal envisioned at the start of the thesis process. Thus, the way of working was found suitable for the thesis project, and was also influenced by pre-determined research objectives.

1.4.2 How do you assess the value of the transferability of your project results?

Since the outcome of the thesis is an experimental methodology, and not a specific product, the result is bound to be transferable. The objective was to maintain a high level of transferability in order to facilitate future research on relevant subjects. As a result, detailed information about the process of development of the experiment including assumptions and exclusions, specification of the components used for prototypes and the electro-pneumatic circuit and codes to control the circuit as well as to analyze the data have been made available in this report. In terms of the results of the façade industry survey, publication of these results for dissemination of information is envisioned for the near future.

1.4.3 Did you encounter moral/ ethical issues or dilemmas during the process? How did you deal with these?

Reduction in the thickness of glass does impact the performance of glazing. At the same time, it raises concerns about safety and durability of the glass and is perceived to be of a lower quality as compared to conventional façade glazing. Given this context, pushing for reduction in glass thickness certainly leads one into a dilemma.

As compared to the technical effects of deformation, this project focuses more on the effect on occupant satisfaction. This approach was challenged and questioned by people from the facade industry during the survey. In addition, there is a uncertainty associated with whether the measured acceptance thresholds of deformation are actually higher than conventional deformation limits or not; and whether this information is sufficient to bring about desired change in the conventional limits.

However, without a scientific approach towards measurement of occupant acceptance, these questions would always remain unanswered. Each dilemma opens up a new avenue for scientific research. Therefore, acceptance of these dilemmas as opportunities rather than barriers was the way one chose to deal with them.

In terms of the façade industry survey and the experiment, one of the challenges was to maintain privacy of the respondents and assure them of the same. The surveys in this research have been designed in lines of the recommendations by HREC of TU Delft, and the data managed accordingly. The respondents are also informed before them filling out the survey that any personal information collected will be stored in a csv format in a safe storage at the TU Delft.

1.4.4 Learning from your own work, reflection on feedback by mentors and translation of feedback into work

The graduation process was crucial in terms of self-learning. The mixed-method research approach demanded a fair amount of knowledge about different sub-topics. While knowledge about new subjects such as building electro-pneumatic systems, designing of a survey and conducting quantitative and qualitative analysis of results was gained, the topic also provided an opportunity to deepen the knowledge about mechanical behavior of façade glazing and limit state design method. Writing contributed to a large

extent to assimilate gathered information in a structured way, reflect on the process and to build a strong narrative for the graduation thesis.

Since the topic lies at the intersection of human-centered façade design and structural design, the mentor-team of Asst. Prof. Alessandra Luna Navarro and Prof. Mauro Overend is a suitable fit for the project. Timely feedback by mentors was a significant part of the progress of this thesis. Their feedback was always well-structured and specific to the problem at hand. This made it easy to translate their feedback into actionable steps. In addition, both the mentors were equally invested in the project, which really helped maintain a positive spirit throughout the research and design process. The project also benefitted from not only their expertise in the subject, but also their extensive industry network, which was responsible for the quality of results achieved from the industry survey and the experiment setup.