Unitized curtain wall systems for non-orthogonal façades
“Solutions for custom-made unitized curtain wall systems for non-orthogonal façades”

Sharon Ligthart
B1275305
Building Technology
International Façade Master
1.0 PREFACE

After finishing the Bachelor degree at TUDelft Architecture, I will now finish my Master degree with this graduation project. This graduation project is part of the track International Façade Master of the Building Technology department on the faculty of Architecture TUDelft.

For this graduation project a research question is defined which will lead to a scientific research.
The main goal of this research is to add new scientific knowledge for the development of the future façade design.
INDEX

1.0 Preface 2

2.0 Summary 5

3.0 Research topic
   3.1 Internship 8
   3.2 Scheldebouw 8
   3.3 Field of research 9
   3.4 Research question 10
   3.5 Research sub questions & Research method 10

4.0 Analysis
   4.1 Design strategy of unitized curtain wall systems 11
      4.1.1 Design components 12
      4.1.2 Design principles 21
      4.1.3 Non-orthogonal profiles 29
      4.1.4 Modified profiles 32
      4.1.5 Design strategy 34
      4.1.6 Site installation of a unitized curtain wall system 35
      4.1.7 Fabrication sequence 40
   4.2. Morphologies of unitized curtain wall system 42
      4.2.1 Morphologies made with unitized curtain wall system 43
   4.3 Non-orthogonal morphologies 44
      4.3.1 Defined shapes of morphologies 45
      4.3.2 Shape surfaces of morphologies 48
      4.3.3 Implementation of design strategy 49
   4.4 Chosen morphology for development of new design strategy 50
      4.4.1 100 Listed non-orthogonal buildings 51
      4.4.2 4 Most common morphologies 53
      4.4.3 Twisted extruder 55
      4.4.4 Line Sweeper 56
      4.4.5 Conclusion selection morphology 57

4.5 Design strategies of non-orthogonal façades 58
   4.5.1 Case studies 59
   4.6 Design strategies of non-orthogonal façades for unitized curtain wall systems 79
      4.6.1 Analysis case studies 80
      4.6.2 Implementation in design strategy for the selected morphology 96
      4.6.3 Conclusion 103

5.0 Final design strategy 104
   5.1 Demands 105
   5.2 Geometry 109
   5.3 Final concept 119

6.0 Conclusions 125

7.0 Reflection 127

8.0 Recommendations 129

Bibliography
Appendix
2.0 SUMMARY

//Summary of the graduation research
The prefabricated unitized façade is the second most well-established façade system. The most significant difference between this type of façade and the post-and-beam façade is the degree of prefabrication. With unit system façades the glass elements as well as certain building services components can be preassembled to a great extent.

The goal is to reduce cost-intensive in situ assembly, minimize work on site, quick installation without scaffolding, establish a high-quality product and to improve cost-estimation.

The unitized façade for high-rise buildings is often combined with the curtain wall system. The curtain walls are suspended from above with the aid of tie rods. This approach has the advantages of avoiding buckling in the posts and of a large degree of independence from the main structure of the building.

Combining the unitized system with the curtain wall system to build a façade is very suitable for straight towers and other orthogonal shaped buildings.

However, nowadays non-orthogonal buildings come more and more into fashion. Architects create buildings, and subsequently façades, with a variety of different morphologies. Depending on the morphology of the façade, a design strategy needs to be developed to meet the external requirements and fit within the unitized curtain wall strategy.

It needs to be investigated whether the current design principles of unitized curtain wall are sufficient and efficient to meet these demands or improved and new design principles for non-orthogonal façades have to be developed.

A small research showed which morphologies could already be made with the current design strategy of the unitized curtain wall system and showed which morphologies need a new design strategy. The number of morphologies that needed a new design strategy was however too big to include all for a new strategy.

To develop an efficient new design strategy it was necessary to focus on only one morphology. To narrow down, an inventory was made of 100 non-orthogonal morphologies as a quest for which non-orthogonal morphology a new design strategy is the most needed.

The inventory showed four morphologies that were the most designed, of which two needed a new design strategy. A short analysis of these two morphologies showed eventually that the 'Twisted Extruder' is the most feasible morphology for the development of a new design strategy.

The overview of strategies of current non-orthogonal façades gave an indication of systems used to build these façades. To see which design principles and design components could be implemented in the new design strategy, the projects were analysed at detail level. Most interesting finding of this analysis was the missing combination of the unitized panel system with the solution to solve the rotation in the connection. Second was the confirmation that the current unitized system can’t handle irregular inclinations or rotations.

Projecting and adjusting the current non-orthogonal façades at the strategy needed for the twisted extruder showed they had the disadvantage it had to be modified for each angle and big open seams were created by rotating the façade elements.
2.0 SUMMARY

For the development of a new design strategy demands were set per design principle and an example project was designed in order to have a more accurate idea of all occurring rotations, inclinations, sizes and angles. The floorplan followed an irregular described curve that provided for both rotations inwards and outwards.

For the glass retention three concept ideas were picked as options to solve the different rotations of the glass panes. These three glass retention concepts were based on existing solutions, but were now modified to also retain glass for different angles. These concept solutions were made with a restricted amount of modifications. The main profile remains unmodified for all different angles.

A ‘worst case scenario’ was developed for the most extreme outward rotation to solve the watertightness. For all smaller outward rotations and all inward rotation, an additional block is placed at the bottom of the mullion to make a watertight connection with the transom. This way only one mullion profile is needed.
3.0 RESEARCH TOPIC

//Field of research and research question
3.0 RESEARCH TOPIC

3.1 INTERNSHIP

At the faculty of Architecture a lot of knowledge is transferred to the students during their education period. This knowledge is very valuable, but in some cases, in my opinion, missing the link with the real practice. The ‘International Façade Master’ of the TUDelft was founded in cooperation with several contacts from the industry and has therefore many contacts with companies out of the façade business.

To broaden my knowledge of façades, I have chosen to do an internship for my graduation project at a company. This way I could see how the design of façades is done in real practice and I could do a research for a problem out the field of work.

For determining a graduation subject, several graduation topics were presented by the International Façade Master. These topics were offered by the TUDelft and the participating companies, under which the company Scheldehouw, offering a topic about “Solutions for non-orthogonal façades”. This subject I found very interesting and after an inventory of graduation topics among other non-participating façade companies, I eventually chose the company Scheldehouw to do my graduation internship on the graduation topic “Solutions for non-orthogonal façades”.

3.2 SCHELDEBOUW B.V.

Scheldehouw B.V., part of the Permasteelisa Group operates in the field of project management, design, fabrication and installation on site of bespoke cladding and curtain walls for buildings in the top segment of the international construction market. The product range and solutions comprises various systems, components and materials, such as active and interactive façades with ventilation, closed cavity double skin façades, sun shading systems, all types of glazing, aluminium, steel, stainless steel, copper, titanium, natural stones, prefab concrete, ceramic materials, synthetic materials etc., including various surface treatments.

The design philosophy of Scheldehouw is based on “thinking on building level” and a “holistic” approach to optimise the integration of all building components and the overall performance of the building in all aspects.

It is also directed to a maximization of prefabrication off-site and fabrication in the factories is focused on end-assembly. This approach results in a better control of quality and short installation times on site.

On the stock market of Milan the listed Permasteelisa Group is one of the world market leaders for specific façades and interior decoration with activities on 4 continents, with a network of 50 companies in 26 countries. The group contains approximately 6000 employees, of which 25% in R&D, design and engineering. The group uses the branch names Permasteelisa, Gartner and Scheldehouw.
3.0 RESEARCH TOPIC

3.3 FIELD OF RESEARCH

Field of research

Many solutions to build a façade are possible, each providing its own possibilities. According to current building trends, almost all buildings now use the systemized façades. Knaack, et al. explains systemized façades are built up out of specific parts of the structure that comprise standardized components provided by façade suppliers. Because technical requirements of façades have increased significantly, they are now fully regulated and can only be fulfilled by adopting sophisticated methods. The necessity for systemizing the façade is therefore obvious, as the high demands of building performance now render the façade a particularly complex building component (2007:44).

A systemized façade can be built according to the unit system façade. The prefabricated unit system façade is the second most well-established façade system. The most significant difference between this type of façade and the post-and-beam façade is according to Knaack, et al. the degree of prefabrication. With unit system façades the glass elements as well as certain building services components can be preassembled to a great extent. The goal is to reduce cost-intensive in situ assembly, minimize work on site, quick installation without scaffolding, establish a high-quality product and to improve cost-estimation. One of the major advantages is that the manufacturing can be shifted to an earlier process phase and assembly can be carried out independent of the weather.

Using systemized solutions always implicates a constraint on creativity because the system product already provides a standardized solution by default. Modification of a system by the architect can only be realized if the manufacturer can anticipate an increase in product market value that ensures a return on the investment. Typically, budget restraints prevent system adaption or new system development. There are exceptions however – mainly in major projects such as high-rise buildings. Here customized solutions may be of interest because of the large number of units needed (2007:46).

The unitized façade for high-rise buildings is often combined with the curtain wall system. The curtain walls are suspended from above with the aid of tie rods. Knaack, et al. state this approach has the advantages of avoiding buckling in the posts and of a large degree of independence from the main structure of the building. The façade can be partitioned almost at will and cladding or glazing used to meet the various esthetic or functional requirements. The vertical and lateral loads are generally led to ground floor by floor, but special load bearing elements may be added to bridge longer spans (2007:27).

Combining the unitized system with the curtain wall system to build a façade is very suitable for straight towers and other orthogonal shaped buildings. However, nowadays non-orthogonal buildings such as faceted and double curved buildings come more and more into fashion. Architects create buildings, and subsequently façades, with a variety of different morphologies. Depending on the morphology of the façade, a design strategy needs to be developed to meet the external requirements and fit within the unitized curtain wall strategy.

It need to be investigated whether the current design principles of unitized curtain wall are sufficient and efficient to meet these demands or improved and new design principles for non-orthogonal façades have to be developed. The focus for this research will be on the systemized design principle for the aluminium or steel framing, which later on can be customized.
3.0 RESEARCH TOPIC

3.4 RESEARCH QUESTION

Can the current design strategy of the unitized curtain wall system fit the design principles for the different morphologies of non-orthogonal façades or does an improved and new principle have to be developed?

- Which morphologies need a new design principle and what could be the design principle of one morphology of the non-orthogonal façades?

3.5 RESEARCH SUB QUESTIONS & RESEARCH METHOD

Investigate the current design strategy of unitized curtain wall systems for orthogonal façades

- Investigate which current unitized curtain wall systems are used
- Investigate which morphologies can already be made with the unitized curtain wall system

Investigate the different non-orthogonal morphologies that are designed by architects and define the ones that require a new design strategy

- Investigate which non-orthogonal morphologies are designed by architects in a time lap of the last 10 years and with a budget above 10 million euro
- Investigate which non-orthogonal morphologies can already be made with the existing design strategy of unitized curtain wall systems
  - Define the non-orthogonal morphologies that require a new design strategy

- Analyse which non-orthogonal morphology will be chosen for the development of a new design strategy

Explore improved and new design strategies for non-orthogonal façades and beacon strategies that can be implemented for unitized curtain wall systems

- Investigate which design strategies for non-orthogonal façades are used by façade-offices
  - Order the strategies by material, component and geometry
  - Focus on framing, anchors and mounting
- Investigate which design strategies for non-orthogonal façades can be implemented in the design strategy of the chosen morphology

Develop a new design strategy for one type of morphology of non-orthogonal façades

- Develop a new design strategy for the analysed type of morphology
- Implement the new design strategy within the design strategy of unitized curtain wall systems

![Diagram showing the research methodology](image-url)