A Building Information Modelling-Based Tool for Heuristically Assessing Façade Manufacturability

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Summary

Reviews of real-world façade project processes have shown that understanding and incorporating manufacturing constraints at early stage design can lead to improved design development. The paper presents a tool to assist façade engineers in the development of panelisation schemes to facilitate manufacture. The tool uses the data stored in project Building Information Modelling (BIM) databases to evaluate the proposed designs against manufacturing constraints. It has been implemented in two ways, the first using a proprietary BIM application and the second using open source International Foundation Classes (IFC) BIM technology and the TNO IFC Engine toolbox. The paper includes a case study of the tool's application to a real world façade project. The principal finding is that implementation through open source technology is preferable due to significantly reduced analysis times arising from accessibility of required design data.

Keywords: *Façade; BIM; design; manufacture; IFC; Design Research Methodology (DRM)*

1. Introduction

Façade engineering suffers from many problems common to the broader construction industry, such as poor communication and fragmented working methods. These can in part be addressed Building Information Modelling (BIM), whose primary benefits include efficient storage, access and transfer of design information, and increased collaborative working [1]. The construction industry as a whole has recently increased its use of BIM.

However, the discipline also faces specific challenges, since building envelopes are constructed from a wide range of materials with a variety of possible treatments. This increases the difficulty in managing manufacturing and installation design constraints. Furthermore, since façade consultants are appointed to provide specialist advice to design teams, the projects in a façade consultant's portfolio tend to be particularly complex in terms of geometry, materials or performance. This leads to design issues such as manufacturability, constructability and maintenance and it is the façade engineer's responsibility to advise the design team on these issues and to assist with design and development of the façade.

1.1 Building Information Modelling

BIM technology is primarily deployed in industry through proprietary applications such as Digital Project, Revit and Microstation. This poses problems such as the introduction of errors and omissions resulting from the transfer of design information between different applications used by different members of the design and construction team. A possible solution to this problem is to standardise on neutral digital information storage formats.

The IFC data model schema is an international open specification designed for the exchange of building information in the construction industry. BuildingSMART, previously the International Alliance for Interoperability (IAI), coordinates the schema development. The schema provides an object model based description of spatial elements, building elements, MEP elements and other building components [2]. The flexibility of the schema is increased by the IFC Property Set attribute, which allows users to include data not currently specified by the schema.

Karhu [3] noted that the IFC data model schema (which was in its early stage development at the time of writing, 1997) offers an industry standard product model that could be applied in this sector. Since then, many projects have used the IFC schema to store and exchange design information, including Sacks *et al*. [4], Sanguinetti *et al*. [5], Mitchell *et al*. [6], Laine *et al*. [7] , and Fazio *et al*. [8]. A common finding is that although the IFC data model schema supports the exchange of design information, the schema is underdeveloped.

Alongside the development of the schema, others such as the Building and Construction Research Group of the Netherlands Organisation for Applied Scientific Research (*Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek*, TNO) [9] have developed tools to facilitate the use of the IFC schema. TNO's IFC Engine toolbox includes a DLL file, making available a selection of C++ methods that can be used to interrogate and modify a BIM IFC file.

1.2 Design Research Methodology (DRM)

The Design Research Methodology developed by Blessing *et al*. [10] is a structured approach to design research projects. Through mapping the influences on design project outcomes, it is possible to identify areas of the design process that could be targeted by the research project. In response, support tools can be developed and tested. This methodology has been employed in the initial phase of the research project to identify the scope of the design support tool.

1.3 Outline of Content to Follow

The following section describes the process used to identify the area of the façade design process that the BIM-based support tool is to target. Section 3 describes the two implementation methods and provides a comparison. Section 4 uses a case study to demonstrate the tool's use on a real-world project. Finally conclusions are drawn and further work outlined.

2. Design Influence Map

The DRM 'design influence map' has been employed in this research project. It is used to identify the part of the design process undertaken by the façade engineer that, if addressed by a support tool, would have a positive impact on the outcome of façade design projects.

2.1 Design Influence Map Production

The maps have been developed through an iterative process, drawing on the experience of façade engineers currently working in the façade sector. First an outline map was developed by the research team after a series of interviews with industry members. This was then reviewed through an interview with a façade engineering team director whose comments and modifications were incorporated into the map. The final iteration consisted of a workshop to elicit knowledge from a team of façade engineers and produce the final map.

2.2 Design Influence Map

An enlarged section of the whole map is shown in Figure 1. Each bubble in the map describes either a design influence or a project outcome. For example, the quality of the scheme review comments passed to the design team influences the quality of the design development undertaken by the design team.

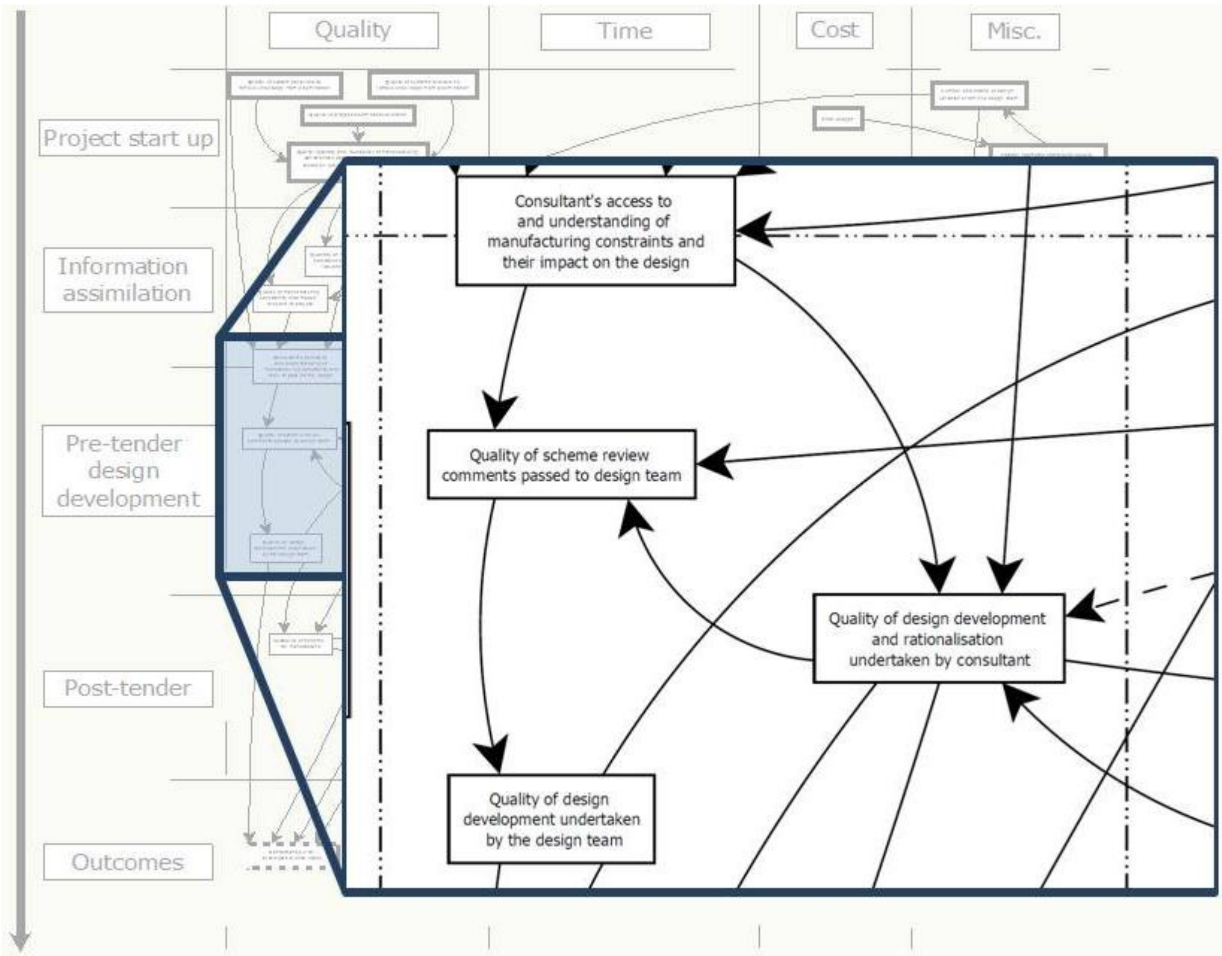

Figure 1: An expanded extract of the Façade Engineering Design Influence Map

By using the DRM it was possible to identify which factors influence the overall construction cost, and the extent to which the final design conforms with the architect's and client's original design intent. Chief among these was *the façade consultant's access to and understanding of manufacturing constraints and the impact of these constraints on the design at pre-tender design stages*. As a result, this is the aspect of the façade engineer's design work that is addressed through the development of a BIM-based support tool described in the following section.

3. BIM-Based Façade Design Support Tool

The tool has been developed to improve the façade consultant's understanding, at pre-tender design stages, of the impact of panel manufacturing constraints on a façade panelisation scheme. It provides the consultant with a heuristic analysis of the manufacturability of the proposed panelisation scheme using design data available from the project BIM database. The constraints on the panel geometry due to manufacturing processes are stored in a knowledge database, detail on capture and access to this heuristic knowledge will not be provided here for brevity. This section focuses on accessing the required design data and analysis of this data.

3.1 Implementation

The tool has been implemented in two configurations. The first uses a proprietary BIM application, which is the main method of deployment of BIM technology in industry. The second uses open source BIM technology which is proposed as a solution to data translation or interoperability problems experienced by industry due to the range of proprietary BIM applications available.

Currently, analyses have been implemented to evaluate three characteristics of panel manufacturability. Analysis of panel curvature is used to predict the ability of the manufacturers to bend the panel to the correct shape. For example, glass with low curvatures can be cold bent into shape, while, above certain curvatures this is not possible and the glass must be sag bent thereby increasing the cost of manufacture significantly. Through discussions with the research project industrial partner, a heuristic curvature measurement was selected. It uses the ratio of the distance from the corner of the panel to a plane defined by three other corners (*H*), to the distance from the corner to the corner diagonally opposite (*L*) (Figure 2). The heuristic curvature is the smallest value of *H/L* found by considering each corner in turn.

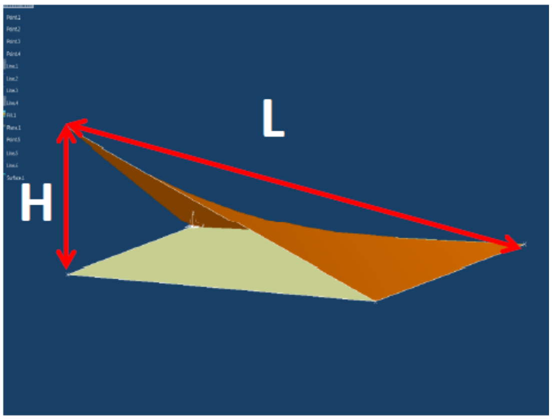

Figure 2: Heuristic curvature measurement

The second analysis implemented finds the value of the minimum corner angle in the plane of the panel. This is a good practice consideration as highly acute angles are easily damaged on site. The final analysis is that of the overall panel dimensions. This is a consideration for a variety of reasons, for example, glass requiring heat treatment in an oven is restricted in size by the dimensions of the oven.

3.1.1 Implementation using Proprietary BIM Application

Since Digital Project (DP) is used by the research project industrial partner as their main BIM application, it was selected for this system configuration.

The building information is stored within the application and is solely accessed through Digital Project. The heuristic geometric analysis is pre-scripted through the Digital Project Visual Basic Application (DP-VBA) scripting interface. The results of the analysis are stored in the main DP design database as an additional element attribute. For ease of deployment to industry, access to the support tool is through the addition of a toolbar available in the main application interface. The user must input the geometrical constraint against which the panels will be assessed.

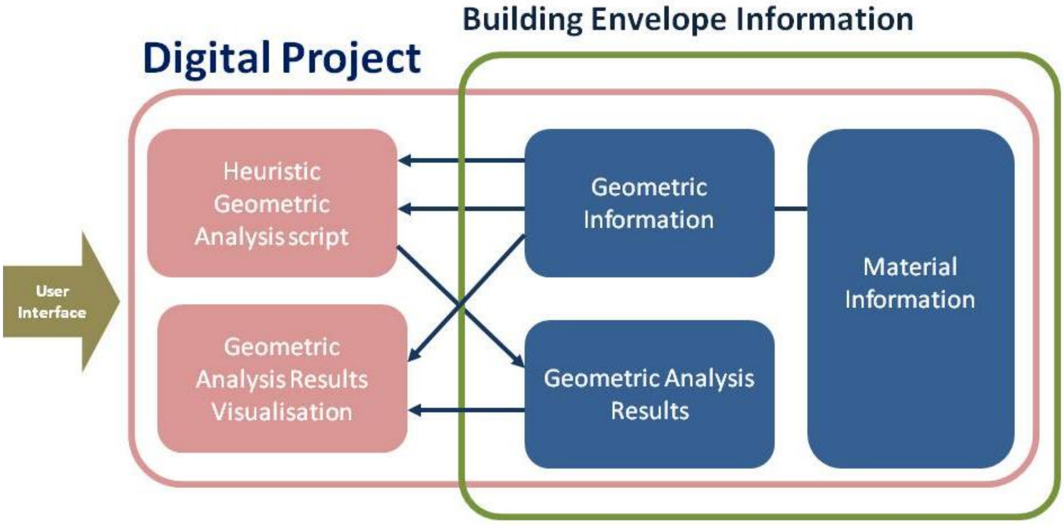

Figure 3: Tool configuration using proprietary application

A key factor in the scripting of the analysis was access to the required design data. The analyses require the coordinates of the vertices of the panels, but, this data is not necessarily made explicit in the model. For example a model imported from elsewhere may only make available a surface representing a panel and not the underlying data (the vertices) used to construct the surface. To extract the required data from the model, various elements of construction geometry have to be generated by the script, increasing the analysis time significantly.

3.1.2 Implementation using Open Source BIM Technology

The second implementation of the system uses open source BIM technology. The building information is stored in IFC format. The IFC file is generated by any proprietary BIM application with IFC export capabilities and the façade panels are made recognisable by defining them as IFC-CurtainWall building elements.

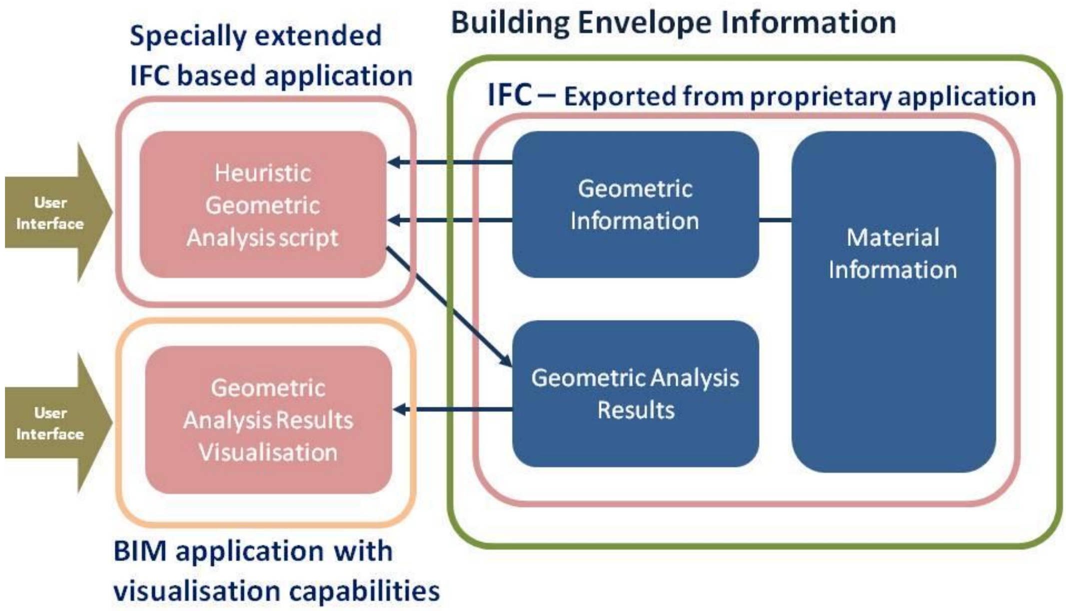

Figure 4: Tool configuration using open source BIM technology

A specially constructed C++ application performs the manufacturability analysis. The application uses the user interface of the TNO IFC Engine example project. The manufacturability algorithm and data extraction uses C++ methods available through the IFC Engine DLL, but has been programmed specifically for this project. The application extracts the required data – the coordinates of the panel vertices – from the IFC file. The required design data is accessible in the IFC file directly, i.e. the coordinate vertices are made explicit and are available through the IFC Engine DLL. The application places the result of the analysis of each panel back in the original IFC file as a bespoke attribute using IFC Property Set class.

The application is executable as a stand-alone program. It requires the user to specify the file name of the IFC file containing the building information model and the IFC schema revision to use. The results can be visualised by importing the analysed IFC file into any BIM application with visualisation functions or attribute interrogation functions. For example, a ‘colour by attribute’ function allows the user to colour the panels according to the results, highlighting those for which analysis results exceed a constraint.

3.2 Comparison of Implementation Methods

The key difference between the two implementation methods is the accessibility of the required design information from this BIM database. Access to the underlying construction geometry is restricted in the proprietary application, but easily accessible through the IFC technology. This made a significant difference in the analysis times for the two system configurations, as discussed in the case study in the next section.

4. Case Study: Astana, Presidential Library

The Presidential Library building in Astana, Kazakhstan is a geometrically complex building, based on a Möbius Strip. The project is from the portfolio of the research project industrial partner, who in the real world project provided advice to the design team and assisted in generating the panelisation scheme. In this case study the BIM-Base support tool described in the previous section is was used to evaluate the manufacturability of the façade and to assist the façade engineer in the iterative development of the panelisation scheme by proving fast feedback on different options

Figure 5: Architect’s representation of the Presidential Library

Image produced by BIG Architects

Both tool system configurations were tested on this project using the same personal computer with 4GB of RAM, operating a Windows 7 32-bit operating system. The tool was used to assess the extent to which the problem of highly acute panel corner angles occurred in the triangular panels. The building was particularly large, with over 40,000 panels.

To run the analysis successfully using the proprietary application the model had to be segmented into 20 sections that where analysed individually and then recombined to visualise the results. This process took a full working day.

Using the IFC- based system configuration, it was possible to perform the whole analysis in 20 minutes. However, the process was limited by the speed of exporting the IFC file from the proprietary application used to construct the building information model.

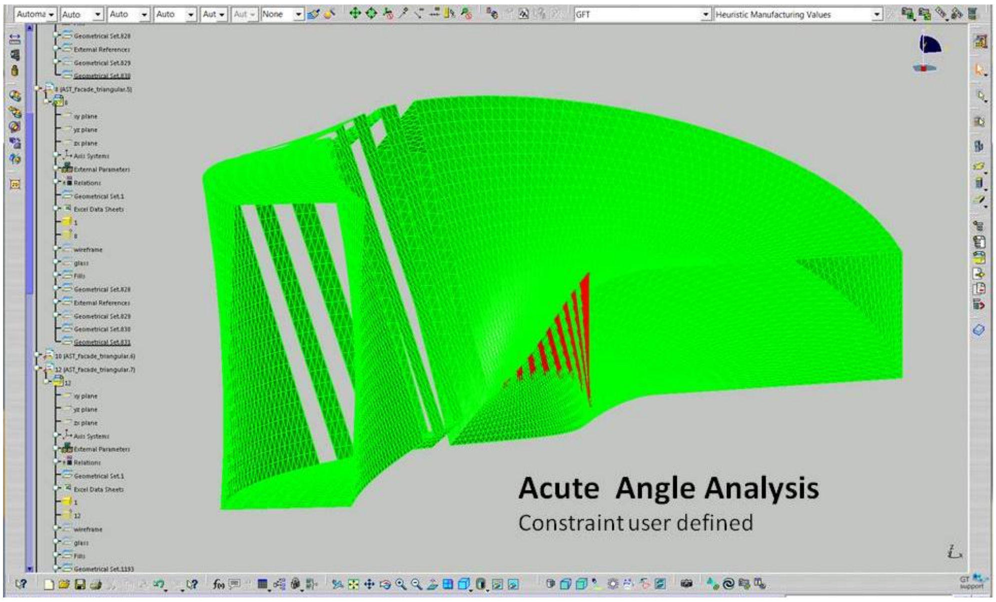

Figure 6: Visualisation of the result of the analysis

The visualisation of the results clearly shows an area of the building where the smallest angle of the panel is less than that recommended by façade engineers (12.5°) [11]. Since the model is constructed parametrically, the parameters can be adjusted and the model re-analysed to rapidly develop the design. In addition, the visualisation and BIM can be used to communicate this design issue to the rest of the design team.

5. Conclusions

The Design Research Methodology has been used successfully, through consultation with industry, to identify areas of the design process to be addressed by the BIM-based support tool.

The implementation of the tool using a proprietary BIM application, Digital Project, highlighted the difficulty in accessing non-explicit design information through the proprietary application's scripting interface. This increases the difficulty in performing non-pre-programmed design analyses and evaluations.

The implementation using open source technology, the IFC file to store design information and the TNO IFC Engine Toolbox, produced a far more rapid analysis. This relied on a small amount of C++ programming which may not be frequently available to members of the construction industry. However, the IFC Engine toolboxes are very useful in this regard, reducing the required programming considerably. The IFC schema was found to be sufficiently defined for this project as the IFC Property Set Class allowed user defined attributes to be included.

The tool has been successfully used to assess the panelisation scheme of a large and geometrically complex real-world project.

6. Further Work

A key area for further work will be to automate the constraint selection by incorporating an additional module in the tool. The constraint selection will be based on building information input by designer describing the material and finish specification of the façade panel. In addition, the incorporation of an optimisation module into the tool will partly automate the design modification phases of design development, and may allow a greater design space to be explored.

Finally, but outside the scope of the broader research project, the tool could be employed to perform analysis for design issues other than manufacturability and constructability, for example, sustainability.

7. Acknowledgements

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