THE MANAGEMENT OF THE DESIGN OF MODERN CURTAIN WALL CLADDING SYSTEMS

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The building envelope is responsible for the protection of its internal environment and has a substantial effect on the energy requirements of a building. The need to increase the efficiency of building façades on account of environmental awareness has given further impetus to the growth of innovation in façade technology. With the advent of new technologies, the specialist knowledge of the façade trade is required. Their early involvement is essential to enable interaction with other consultants and facilitate the production of detailed designs. The pressure on all participants of the supply chain to constantly innovate new processes as well as maintain the tight design and construction schedule; created the need to understand the scale of this production task and to plan and manage it accordingly. Design management research usually deals with the processes within the professional design team and yet, in the UK, the volume of the total project information produced by the specialist trade contractors equals or exceeds that produced by the design team. This paper explores the nature of the specialists' information production process with a view to developing an understanding of the process of design within this area of design and information production in order that the scope and scale can be planned as an integral part of the whole design process.

Keywords: cladding, curtain wall, design, management, procurement.

INTRODUCTION

The need to increase the efficiency of building façades on account of environmental awareness has given further impetus to the growth of innovation in façade technology. The arrival of new cladding technologies adds complexity to the cladding design and information production process and makes it crucial to understand it. Cladding technologies are complex and the specialist contractors' are involved in their manufacture (Gibb, 1999). The specialist facade contractor makes many of the material and component purchasing decisions and takes an active part in most procurement stages, from scheme design and detailed design until construction and maintenance (Ledbetter, 2001).

Innovation can be initiated by various participants of the supply chain; specialist trade designers, fabricators and architects/cladding consultants and engineers. Architects are driven to develop new facade designs for a unique appearance and better performance. However, they are not always completely aware of the technical aspects which make

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them heavily dependent on cladding specialist trade designers. Architect's are to some extent responsible for innovation, particularly at the upper end of the cladding market where style is of real commercial significance. Their interest is strongly project-specific and mainly at the system performance level. They view the cladding system as part of a larger building system and as part of a solution to a unique design problem. However, cladding specialist trade designers are the ones who determine what is on offer and what makes sense commercially both for themselves and for their fabricators (Connaughton *et al.,* 1994). They also provide fabricators with technical support, including interpretation of specifications, thermal and structural calculations and design charts, manufacturing advice and training (Ledbetter, 1997). The influence of cladding specialist trades on innovation is considerable on both system level and material or component level. They are concerned with the system and its components performance and they contribute their knowledge and experience of what works best (Connaughton et al 1994). For the management of cladding design and production processes the key issues are the volume, timing, iterations and information exchange between the parties. This paper looks at the design information production trends during the past two decades and updates them with data from a study of a building project that was completed in 2007. The façade drawings data was analysed to illustrate the importance of understanding and managing the design information production process of façade systems. A generic process map of façade design from project inception to final specification of cladding was produced to identify significant interface management issues between the façade and the structure. The design of the facades and its connection to the structural frame was investigated in more detail during the information production and cladding installation stages, where the exchange of information between the cladding specialist's and the structural engineer is at its highest and the production of the project information intensifies.

INFORMATION REQUIREMENTS FROM CLADDING SPECIALISTS

Cladding design and production process is influenced by the overall project design and construction process. Hence, the level of innovation in the cladding design and production would be driven or stifled by the conditions of building industry (Gann D. 2000). The majority of the studies of design information production concentrate on that produced by the consultant team in the early stages of the design process as defined by the RIBA plan of work. However, this framework was criticized by Gray and Hughes (2001) in that detail design, production information and shop drawings, for component based construction, are a continuum more properly called 'engineering design'. The bulk of the information that is produced for engineering design involves the integration of the specialist trades' design into the whole. The scale of specialist contractors' involvement in the whole of the project information production process is extensive. Freeman (1981) in a review of comparative studies of UK and US practice, noted that Eden and Green in a study of US hospitals had found that for a 300-bed hospital, the design team produced 204 drawings and the specialist more than 3000. In a study of seven UK projects, reported by Gray (1999), the percentage of the total drawings produced by the specialist trade contractors on a typical UK building project was 42%, with a range of 10–75%. The Senator House study (Steel Construction Institute, 1993) reported that the design and fabrication drawings for a steel frame comprising 2930 pieces of steel, required 1200 structural consultant drawings and more than 2000 fabrication (shop) drawings.

A study of a £130m tower building in the City of London was used as it had the same characteristics as the Senator House study. The scheme design started at the beginning of 2004, the enabling works started at the beginning of 2005 and the project was completed in 2007. The principal contractor was a construction management appointment, while the trade contractors' agreements were a mixture. Some were straight tender and lump sum; some were two-stage lump sum. There were approximately 30 major suppliers on this project. This study showed that the total number of drawings on this project was 17,868, the percentage of the total drawings produced by the specialist trade contractors was 64% which amounted to 11,447 drawings while the percentage of the total drawings produced by the architect was 21.5%, which amounted to 3,844 drawings. Other consultant's total number of drawings was 2,579 which is 14.5% of the total number of drawings. 62% of the drawings are issued once while 38% of the drawings go through a number of iterations until they are finalised. 18% have two iterations and 9% have three iterations. These iterations increased the total number of drawings from an original 9172 to 17868. In this study, 15% of the total project drawings were produced by the façade specialist trades.

Drawings Volume, Timing and Iterations

Figure 1 makes a comparison between the number of drawings produced against the programme and it shows that during the production information stage the number of specialist trades drawings produced peaks while the number of drawings produced by the architect and other consultants drops. However, the number of architects and other consultants' drawings increase as well as the number of drawings produced by the specialist trade contractors when the mechanical and electrical installations start. Then towards the end of the construction stage, the drawings produced by the specialist trades and the architect have more or less the same pattern, while the number of drawings produced by other consultants declines. The final peak is for the "As-built" drawings.

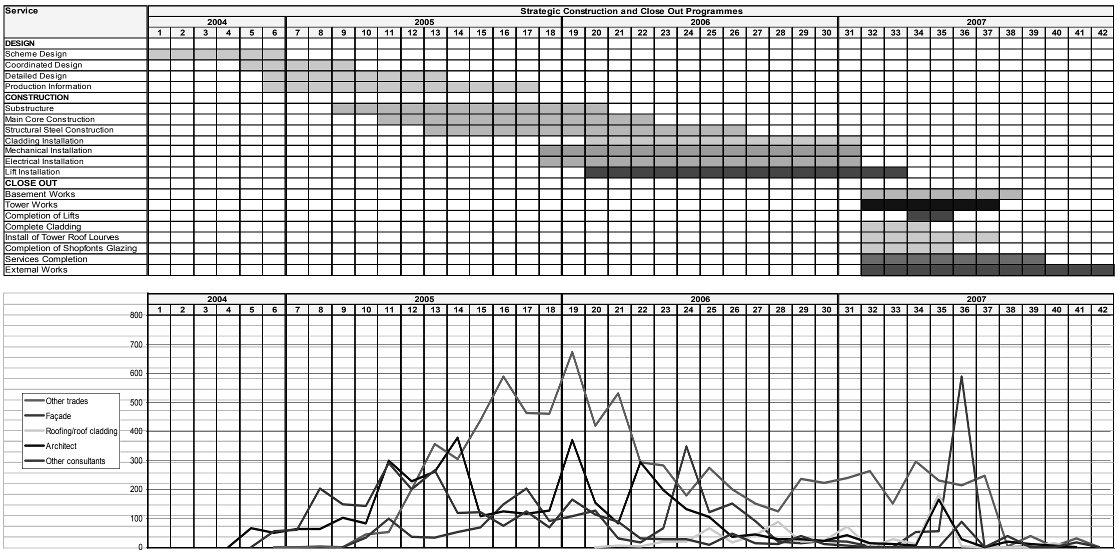

Figure 1: Number of drawings against the programme

Figure 2 first chart shows the trend of iterations over the time of the project. This chart was produced by summing the number of drawings, except for issues with number 1, as all the subsequent issues are in fact iterations. The second chart is the finalisation pattern for each discipline against the programme. This pattern was produced by including the final issue of each drawing only and excluding drawings with zero iteration and "As Built" drawings. Figure 2-a; shows that iterations increase during the production information stage and continue to the construction stage well after the cladding, mechanical and electrical installations start. The finalisation process of architectural drawings peaks sharply after the cladding, mechanical and electrical installations start, which could be the result of the architects being able at this stage to get the necessary information from the specialist trades to finalise their design (figure 2-b). However this needs to be explored further.

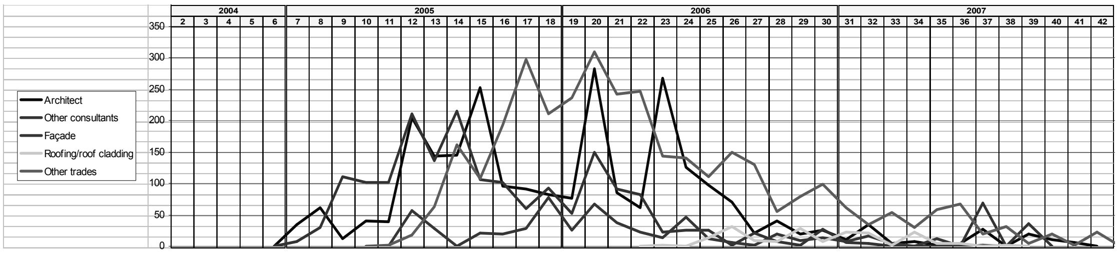

Figure 2-a Drawing iterations trend over the time of the project

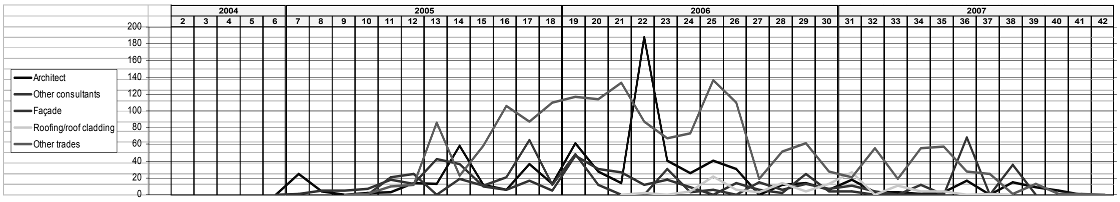

Figure 2-b Drawings finalisation trend over the time of the project

Figure 1 shows that the number of façade drawings produced peaks twice, once during the production information stage and then in the middle of the façade installation stage. The iterative process is also high during the same stages (figure 2-a) as well as the finalisation process (figure 2-b). Therefore it is important to understand and manage the design and the information production process of the façade system during these two stages. This study shows that the major issue of design management these days is still the same as it was for the past two decades.

Cladding design decisions could be seen as the result of the interaction between the knowledge and the skills of the cladding designers and the information they have received about the problem from the other designers involved in the design process, the client and others (Gray and Al-Bizri, 2007). The cladding designers need information to select among various alternative actions, the outcomes of which cannot be distinguished between them without the information. In order to understand the process of cladding design and information production, an attempt is made to model it in sufficient detail to understand its scope and scale. Façade design and its connection to a structural frame was chosen to develop this model, as it is a typically complex component interface.

UNDERSTANDING THE DESIGN INFORMATION PRODUCTION PROCESS OF FAÇADE SYSTEM

A generic process map was produced (Figure 3) that shows the interface between the façade design and the building structure design. This is based on a process map prepared by Gibb and Pavitt (2003). The aim of this process map is to identify significant interface management actions and decisions between the façade design

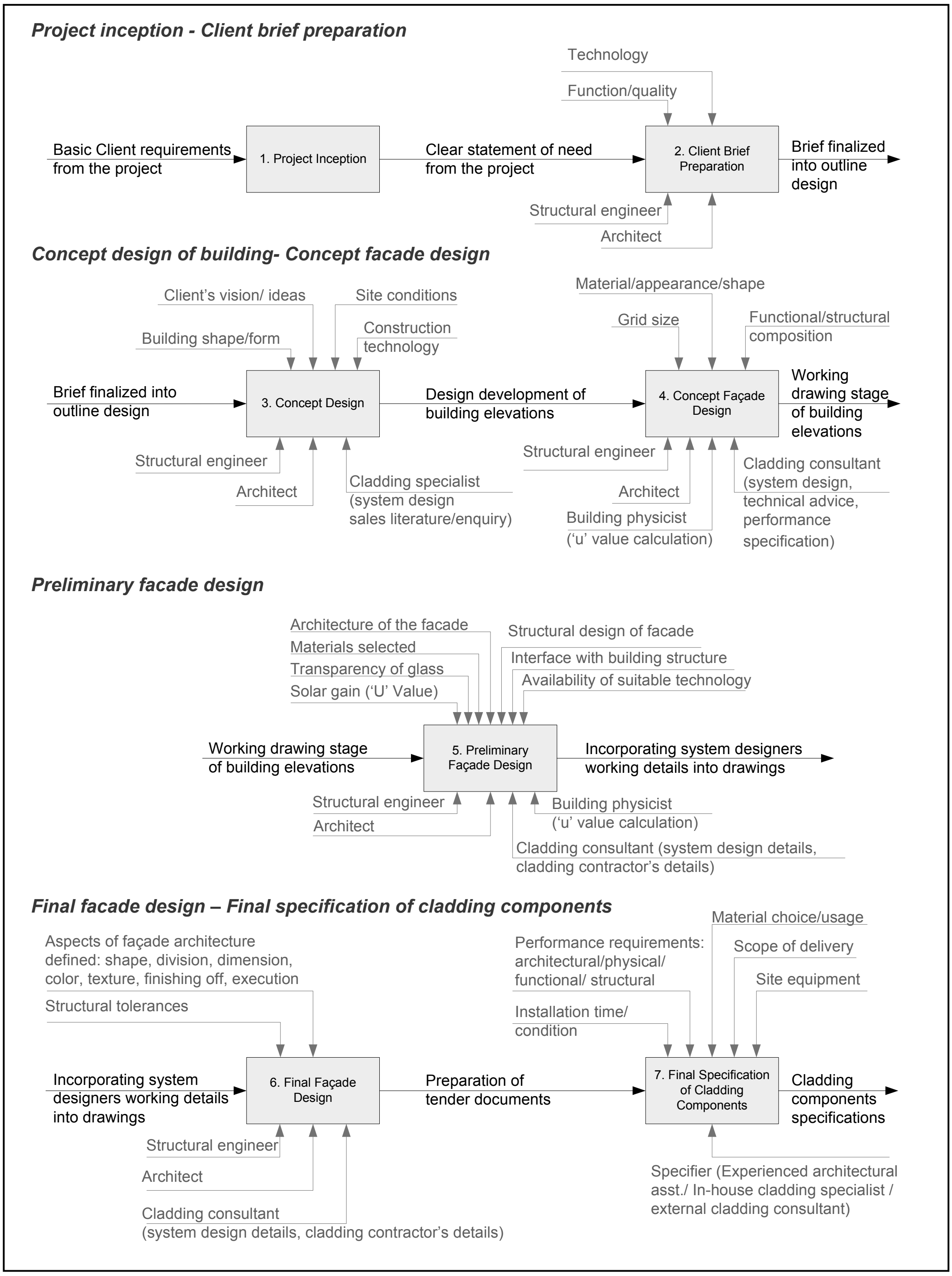

Figure 3: Cladding system design process map

process and the building structure using IDEF0 techniques. This process map identifies the main participants, their roles, the stage and extent of their contribution and project constraints/guidelines. Understanding the interface between the façade design and the structure gives a clearer picture as to how the cladding industry actually works. The sequence of events on a bespoke cladding project might not be any different from the path described, except that the specialists would be brought in earlier and the number of iterations is likely to increase due to its one-off nature.

On a bespoke project, it is important that the client selects a design team and later a contractor, not just on price but on their ability to develop the design using their manufacturing and construction knowledge, experience and their ability to innovate. This is followed by the client brief preparation by the design team. Proposed budget, completion time, quality and functional requirements should be specified in the brief in sufficient details not only to retain the integrity of the project, but also to be flexible to allow the contractor's design team to innovate whilst still remaining in the boundary of the brief (Pask *et al.,* 1999). During the concept design stage, the building elevations are developed by the architect, the structural engineers and the cladding specialists.

The cladding consultant develops the design concept of the façade from the sketch elevations provided in the architect's approved concept design. The decisions on functional and structural composition, the shape, the grid size of panels and the material determining its appearance are the result of the interaction of the expert knowledge of the cladding and structural consultants. The architect may procure the services of the cladding consultants from the system designer, cladding subcontractor or specialist consultancy. A building physicist (usually a part of the consultant's team) would help calculate the 'u' values of the building to check for overall performance of the façade as an element of the built facility as per the Part 'L' regulations.

At the preliminary façade design stage the architect and the cladding consultant further develop the architecture of the façade and select its materials and determine; its appearance, the transparency of glass panels, the techniques to control radiation, and the use of solar energy. The structural engineer makes decisions on the method of attaching the façade panels to the structural frame of the building with tolerances, movements, etc. In keeping with the part 'L' regulations, the façade design is considered in conjunction with the HVAC installations.

Finer details of façade architecture are defined: shape, division, dimension, execution colour, texture and the finishing off. In addition installations for ventilation, measures for maintenance and repair, structural and physical aspects and the safety and comfort conditions are worked out. The cladding consultant assists in the preparation/review of tender documentation and assesses tender submissions from subcontractors bidding for the work.

The specification of façade components and materials is a continuous process that goes hand in hand with the design of the cladding system. This function comprises the specification of performance requirements of the architectural, structural, physical and functional aspects of the cladding system. Furthermore, the use of material, scope of delivery, administrative conditions, time requirements for building phases, installation conditions and the equipment on site are set up at this stage. The system manufacturer may also be invited to work out the façade specifications. This is particularly important in the case of a new or special façade designs as the expert support of the manufacturer is required for working out the performance specifications of the cladding system (Karsai, 1997).

Cladding Design Iterative Loop

Figure 3 shows that; the involvement of the cladding specialists in the project could be as early as the concept design however their contribution intensifies in the subsequent stages, particularly during the information production and cladding installation stages (figure 2). An extensive design iterative loop takes place at the preliminary façade design, final façade design and final specification of cladding component processes (figure 3). Here is where the involvement of the cladding specialist contractors' is at its uppermost and the exchange of information between them and the structural engineers and the production of the project information intensifies. The information produced in this iterative loop hits the highest point and the need for the cladding specialist contractors to communicate with the team is crucial to integrate the cladding system design into the project. The design of facades and its connection to the structural frame is one of the more complex processes on a building project. The structural design of the façade and its interface with the building structure showed in figure 3 are investigated in the following section in more details in order to understand it and to manage it.

Information Exchange between the Cladding Specialist Contractor and Structural Engineer

Figure 4 looks at the cladding panel design and its connection to a structural frame. Cladding panels are usually non-load-bearing, but load-bearing panels are used when they provide the most economic structural solution. Designing non-load-bearing cladding panels and their connection to the structural frame is a complex process, which involves designers from different design teams and organizations. The architect, structural engineer and cladding specialists are usually involved. The specialist has to determine every requirement for each panel and instance. So the following is repeated for every panel type where there is a change so that the manufacturing process can make the right panel.

The design of non-load-bearing cladding is highly interdependent with the structural frame. The units and their fixings are designed to withstand panel self-weight, wind loads and the lifting and handling stresses during manufacture and erection. The process of designing non-load-bearing panels and their relationship to the structure involves the architect, structural engineer and the trade contractor.

The precise dimensions of the panel are determined by the architectural and structural requirements, the practicality of manufacture, the transportation and weight of unit for lifting. From the input information of elevation and detail drawings, the cladding designer determines the panel's width and length. The precise structure of the panels is a function of many considerations. However, the self-weight of the unit and the fixing methodology are the most important for the structural engineer. For each fixing location to the structure, the structural engineers should check the loads on the structure as it may affect the column dimensions and spacing. Also the structural engineer should consider the effect of the weight of the cladding panels on the edge detail of the structural slabs. Information about the edge of the structural slabs and the column dimensions are exchanged between the structural engineer and the cladding designer in order to determine the panel dimensions and shape. This is the first iterative loop between the specialist and the design team.

There are two main types of panel – mullion and spandrel units. A mullion panel extends from floor to floor while a spandrel panel spans between columns or from window to window. The architectural drawings provide the cladding designer with information about the height of the panels, but the design of the structural slabs affects the decision on the height of the panels as their depth can affect the height of the spandrel panels and the floor-to-floor height; therefore, this will affect the height of the mullion.

The cladding designer should provide the structural engineer with information about the fixings that will be used, as the choice of cleats, dowels or other type of fixing affects the design of the fixing points at the edge of the structural slabs. When the cladding designer chooses cleats, the structural engineer can choose between cast-in channels, cast-in sockets, drilled-in sockets or bolts with expanding sleeves depending on reinforcement density. Channels are the preferred method. If the cladding designer chooses dowels, the structural engineer has to consider how to provide the pockets at the edge of the slab, with the resulting demand on casting accuracy.

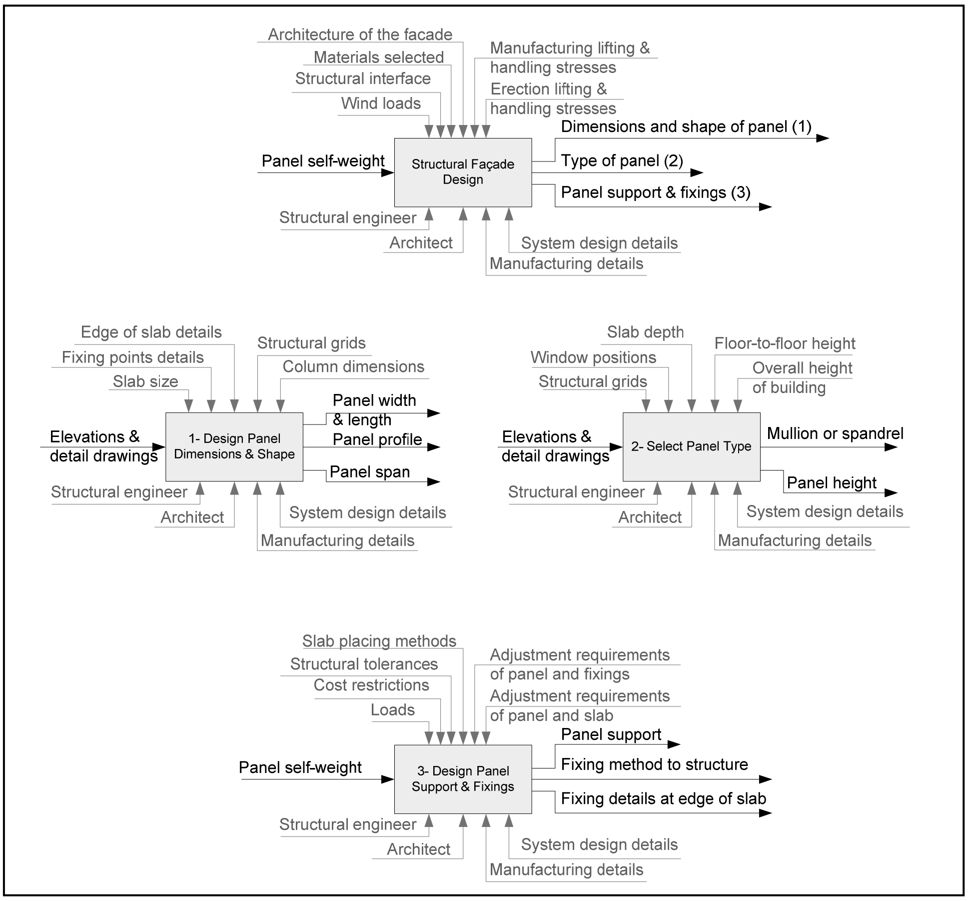

Figure 4: Cladding panel design and its connection to a structural frame

CONCLUSION

Façades today not only have to fulfil functional and aesthetic requirements, they also have to consider emerging technologies, the whole life performance issues and current building regulations. Façade technology has to keep pace with the new requirements, warranting the innovation of new products and services to suit the necessary criteria. Therefore the communication routes of the cladding specialists with the project team become more complex, creating multi-tier hierarchies in the process. Multi disciplinary teams are now required as structural and services inputs are important in the initial phases of the project and the early involvement of the cladding specialists becomes necessary for their knowledge and skills to be incorporated in the design and for the assembly issues to be resolved.

The timing of the cladding design input is crucial in order to reduce the number of iterations. The iterative loops are at their highest during the construction stage. Almost half the number of drawings were reused and reissued, some up to 20 times. The argument is that any reduction in the number of iterations could reduce the design and management efforts required to produce the same piece of information. By process mapping the drawing process the complexity of the information exchange is apparent. In practice this must be done for each drawing or output, which is very complex and time consuming and therefore, rarely done. Understanding the potential failure points, however, is essential to manage the process effectively. Further work on similar data sets would enable a clearer picture of how the process works and where improvements would be made.

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