Computer-Integrated Manufacture of Cladding Systems

RAIS Final Report

1.0 Introduction

This report presents work undertaken at Whitby Bird & Partners' (WBP) Façade Engineering Group and funded by EPSRC under the RAIS programme.

The work is an industry-focused extension to the CIMclad (computer-integrated manufacture of cladding systems) research project (www.cimclad.com) which investigated the feasibility of improving the efficiency and competitiveness of the cladding sector through the development of a standardisation framework for computer-integrated design and manufacture of cladding systems. Owing to the timescale for the CIMclad project, industrial deployment was limited to the product model prototype software. However, CIMclad Report 7 (available on the project website) on a CIM roadmap for the cladding sector made recommendations on the way forward for the cladding sector to fully maximise and exploit the benefits of CIM. A key requirement was the need for organizations involved in the cladding work package delivery process to integrate and align their processes to the CIM working model that focuses on cladding information management and exchange. This work assesses the implications for CIM working model within a facade engineering practice, drawing from the Group's practice. Sector-wide implications of the cultural shift in the current industry practice and the technical issues it will contend with were discussed in CIMclad Report 7.

CIM in the context of this report refers to computer-integrated manufacture of cladding systems for a building project. This involves a process where the scheme design information of the cladding is transmitted digitally to the organisation responsible for the detailed design, and the subsequent fabrication of the cladding components is computer-controlled without the need for paper documents. Indeed, this digital integration needs to extend beyond manufacture through to stocking, dispatch and on-site installation. The CIM working model focuses on the use of cladding product model to integrate the information requirements of a project delivery process across organisational boundaries, from scheme design through to the detailed design, and the manufacturing process.

The initial objectives of the work programme were:

i. To develop the information management aspect of the ‘CIMclad Roadmap’ framework into detailed process and data models.
ii. To map related in-house processes, for example steel and concrete delivery processes, and to test the robustness and suitability of the CIMclad approach to other sectors.
iii. To deploy and evaluate the impact of the models on WBP’s cladding supply chain business processes.
iv. To train industry staff on the use of the product model (pm) software developed in the CIMclad project, assess its efficacy, and identify areas for future revisions.
v. To disseminate the results of the work, focusing on industry uptake issues, through publications in journals and practitioner’s magazines.

Several project meetings were held, primarily to review actual work against planned programme and revise targets as necessary. The project immensely benefited from meetings and interactions with WBP staff at all levels (particularly those of the Facade Engineering and Technology Groups), feedback from presentations to cross-teams (Facades and Technology) and WBP directors, and meetings with external organisations (predominantly WBP delivery chain partners).

This report summarises the main aspects of the RAIS work. Section 2 begins with an overview of façade engineering practice. It goes on to present the work undertaken under the different work packages, aligned to above objectives. This includes developing a facade work package delivery map that identifies activities and information flows typically occurring in a façade engineering practice. Section 3 discusses the implications of facade engineering practice for the CIM working model. It also proposes changes to the current practice and structure necessary to take advantage of competitive opportunities that will be created when the vision of CIM becomes a reality. The CIM vision entails complete integration and automation of the design and fabrication processes for building cladding systems, all functioning under computer control and only digital information tying them together. Conclusions and recommendations are given in Section 4.
2.0 RAIS work

2.1 Process mapping and analysis

WBP Façade Engineering Group operates within a multi-disciplinary consulting engineering practice, Whitby Bird & Partners. Their role in new-build projects is typically upstream of the project process, where together with the project architect and others, they constitute the building envelope design team. The Group's scope of work also extends downstream to the review of fabrication and installation activities including diagnostics/troubleshooting on cladding projects. Upstream of the project process, the Group is typically involved in creating the information necessary for the detailed cladding design to commence. Thus, they undertake a wide range of tasks/activities, which vary with the project stage, to produce the required outputs/information.

A significant proportion of the Group's project-related facade information output is created from computer-based tasks, however, transfers and exchanges with upstream and downstream project parties are in both paper and digital formats. The Group occasionally uses the services of an in-house CAD development team to model building envelope elements - walls and roof.

This phase of work mapped the façade work package delivery process including analysis to establish the characteristics of façade engineering practice. The latter is the basis for assessing the implications of CIM in working practice given in Section 3. The mapping process benefited from direct input from WBP and a number of the Group's project delivery chain partners. The cross-organisational approach adopted helped to clearly define organisational interfaces and brought to fore the key information transfers to be taken into account in the CIM working model. The IDEF0 map developed identifies key activities critical to the delivery process, inputs and outputs, those involved and controls.

Of the five projects (at different stages of completion) examined, detailed case studies were undertaken on two projects, the £200m BBC West One new broadcasting complex and the £12m Hurlingham Phase II sports club development. Analysis of the façade work package delivery process identified a number of key characteristics. The flow of information between collaborating organisations is in all directions, particularly during the design development to tender phase. Depending on the task/activity, the façade engineer can be either a receiver or provider of information, or both. Information complexity increases further down the delivery chain, from outline scheme design to cladding fabrication and installation, and organizational strategies are more closely aligned to their internal business process than to the external project delivery process. This calls for greater integration across the delivery chain.

2.2 Process map deployment and assessment

WBP suggested extending the scope of work beyond issues relating to CIM uptake to ways of improving the current project delivery process. Feedback from presentations on "Improving project delivery process" to WBP Technology and Facade teams, and directors focused on how to convert or translate the process maps into practical tools. The expectation was to deploy the derived tools to add-value to the current practice. Paper-based deployment was advised and found appropriate at the time. A number of process enabling practical tools that could be derived from the process maps were investigated initially. They include tools for activity briefing, activity based costing and management, and information required schedule for project programming. These practical tools have potential applications in managing, measuring or benchmarking activities for continuous improvement. Detailed deployment focused on activity briefing and comprehensive sheets have been produced which also indicate information required at each stage of façade project delivery process. Isao Masumoto, a Loughborough University Engineering Doctorate candidate and Research Engineer with WBP Technology Group is currently deploying this tool in another specialist group within WBP. A practice-wide roll out is envisaged in the near future.

2.3 Related process mapping

It was originally intended, as stated in the objectives given in Section 1.0 (Item (ii)), to map related in-house WBP processes, for example steel and concrete delivery processes, to test the robustness and suitability of the CIMclad product modelling approach to other sectors. However, the project steering committee decided to re-focus this objective to mapping the interfaces between the technical, management, and financial processes. The information yielded from the revised objective is considered more appropriate to issues bearing on CIM uptake. Project/risk and financial management processes are an integral part of any project delivery process but not reflected in the CIM working model definition. This reinforced the case for a revision of this objective.
High-level maps, identifying the crossovers of the three internal core processes were developed. A simplified diagram of the project delivery process is shown in Figure 2. The figure shows that the three internal processes are interwoven and concurrent, and all combine to produce Whitby Bird and Partners' project deliverables. The implication for CIM of the internal project delivery processes is summarised in Section 3.

![Diagram of project delivery process](image)

**Figure 2: Simplified WBP project delivery process**

### 2.4 Knowledge transfer and RA training

The CIMclad concept and its benefits have been formally and informally introduced and explained to relevant staff of the host organisation and a number of their façade work package delivery chain partners. This has been through formal presentations to cross teams and WBP directors, informal team meetings, personal briefings and interaction, and external meetings and interviews with delivery chain partners to gather information for the process mapping work. Presentations have been well received and the feedback has been extremely useful and added value to the work particularly in relation to demonstrating its potential benefits to the practice. WBP directors have agreed further research work on the basis of work reported here.

As was proposed, training was given to staff of the host organisation on the use of the product model software (output of the CIMclad project) to capture and convey engineering information relating to rainscreen cladding from scheme design into full design. Unfortunately, anticipated feedback that would have informed future revisions of the prototype software was limited owing to the Group's lack of recent work involving rainscreen cladding.

The researcher seconded to WBP, Dr Emeka Agbasi, has gained a deeper understanding of issues relating to CIM implementation within an industry setting, the cladding sector in particular. These issues are summarised in Section 3. They have added to his overall experience on the use of ICT (Information and Communications Technologies) to leverage construction business performance.

### 2.5 Dissemination

The work undertaken under the RAIS programme has been disseminated through a number of channels including personal interactions with the Group's cladding work package delivery chain partners and information flyers distributed at focused meetings. Also a magazine article based on this work and titled "Realising the benefits of computer-integrated manufacture of cladding systems" has been published by the Institution of Civil Engineers' magazine: Innovation and Research Focus (IRF No. 52) February 2003 edition (http://www.innovationandresearchfocus.org.uk/). Draft copies of two papers titled "Cladding sector road map for realising the CIM vision" and "Implications for CIM of façades engineer's delivery process" have been completed and will be submitted for publication in a journal and industry magazine respectively.
3.0 Implications for CIM working model

This section focuses on process and practice-related issues but at an organisational level from the viewpoint of façade engineering practice including key business related issues. The implications for CIM of the current façade designers’ practice, particularly in relation to a global CIM-enabling cladding product model that addresses the information and data requirements are highlighted below.

Organisational issues

- The CIM working model, driven by the use of a cladding product model as the means of capturing and exchanging cladding information, is not applicable in all spheres of façade engineering practice. For instance, where a façade engineer is engaged in an advisory or troubleshooting capacity that requires a one-off report for the client.

- Information for internal business functions such as project/risk and financial management that forms an integral part of any organisation’ project delivery process is not captured in a cladding product model. Without adequately aligning the internal business processes to the external project process driven by a cladding product model bottlenecks are bound to occur.

- Facade design development is essentially an iterative process and this characteristic should and could be supported in the CIM working model. This will potentially reduce the design loop or changes in the detailed design associated with missing or insufficient information in the concept design and/or specification. This approach also supports documentation of the design trail.

Delivery chain issues

- A significant proportion of facades engineers’ project workload occurs in the upstream phase - design development to tender. Thus, they are a part of the ‘design chain’ for facade work package. Typically, they collaborate and co-ordinate their roles with other organisations, such as architects, structural engineers, M&E engineers, cost consultants etc, to produce facade design information. The implication for the CIM working model is to facilitate both the delivery chain's short-term project domain process and long-term internal business domain process. To achieve this, all organisations involved in the facades delivery chain should align both processes to ensure effective information management across organisational boundaries.

- Increasing project partnering or collaborative arrangements where all the project team is involved at inception provide an opportunity to agree on the use of cladding product model as a collaborative tool. In general such collaborations are facilitated by effective communication and information exchange between the parties involved. Consequently, this supports the case for using the cladding product model as a collaborative tool.

- It must be noted that it requires the whole facade work package delivery chain’s commitment to adopt the CIM working model to realise its potential benefits. Disconnects within the delivery chain could render the delivery process ineffective and inefficient, and may not justify the adoption of the CIM working model. Therefore, it is necessary for all organisations (architects, facade engineers, and cladding fabricators and installers) involved in the project delivery process to reach a consensus on the use of an industry agreed cladding product model as a standard for information exchange.

Business process integration

As earlier observed, the CIM-enabling cladding product model only emphasises integration and co-ordination of external project-related cladding information. However, internal business activities such as project/risk and financial management impact on the external project delivery process. Hence to ensure an efficient and effective facade work package delivery process, the internal business process has to be aligned to the CIM working model. The strategy proposed is illustrated in Figure 2 and embodied in the CIM activity model (CAM). The CAM fits in the intersection of the three processes. This intersection provides a rational basis for identifying key enabling project-related activities for generating data and information requirements of cladding product model at the organisational level.

The CAM concept is essentially an interface activity model that maps and captures absolutely key internal organisational activities (engineering and business processes - technical, project/risk and financial management) required for producing cladding product model information. Hence the CAM captures key mutually inclusive activities central to populating the cladding product model. It is necessary that project delivery chain organisations analyse their internal business and identify key activities that constitute CAM. With respect to WBP Façade Engineering Group, CAM will include activities that generate the following information to ensure that the information requirements of the cladding model are timely generated:
As previously stated, the cladding product model is a key enabler of the CIM working model. Figure 3 illustrates the two key activity interfaces in the design and manufacture of project-specific cladding (i.e. scheme to detailed design and detailed design to fabrication) and shows two distinct cladding sub-models denoted 2D PM and 2D+ PM as developed in the CIMclad project.

The first sub-model (as developed for rainscreen cladding in the CIMclad project) captures the requirements against which the cladding scheme design was developed, and the proposed scheme. It is essentially two-dimensional since its role is to capture the concept scheme as “painted” onto the elevations of the building. The second sub-model needs to define the details of the components and thus must include more geometric information.

The first sub-model captures upstream information requirements, which is also the main activity domain of façade engineers. Therefore, a global 2D PM should capture a majority of, if not all, the data and information requirements as outlined in the facade process map developed in this work. Also how much of the information transactions between facade engineers and facade delivery chain partners can be effectively and efficiently communicated digitally using the cladding product model, have to be assessed.
Data and information format issues to be taken into consideration to avoid unnecessary duplication when populating the product model include:

- Document or data format, or both. Most of WBP Façade Engineering Group's engineering deliverables are in document (text) format, for example performance specifications, with exception of drawings, and
- How closely the cladding product model information and data structure represent the internal views of the facade engineer.

In general it is anticipated that computer integration of upstream design and downstream fabrication activities will improve the facade work package delivery process.

### 4.0 Conclusions and recommendations

The key conclusions are:

- The CIM working model is a concept that seeks to integrate the facade work package delivery process to realise the vision of computer-integrated manufacture of building-specific cladding systems. Integration of the facade work package delivery process is reliant on a cladding product model that captures the information requirements of the delivery process across organisational boundaries, from scheme design through to the detailed design, and the manufacturing process.
- This study has mapped information transactions in the delivery process of facade work packages. The information and data captured in the maps will contribute toward the development of an industry agreed global cladding product model and reflects the perspective of facade engineering practice.
- The maps and activity briefing sheets spanning the whole project process have defined facade engineers’ information requirements, outputs, and interfaces required to facilitate project team collaboration.
- The maps bring into focus data and information format issues that need to be taken into account in the cladding product model to make it relevant to a facade engineering practice. The project outputs largely exist in document and graphical formats. How closely the cladding model captures the information and data structures of the facade engineer have a bearing on the uptake of the CIM working model.
- Hitherto semi-structured facade work package information has been exchanged in the design development stage where the facade engineer's workload is significant. Improvements in the information exchange interface between an organisation's internal process and the external project process driven by the cladding product model are seen as key enablers of process integration. The CIM activity model (CAM) concept is proposed to capture and align key organisational activities relevant to the generation of cladding product model information. In essence, it is intended to aggregate an organisation's mutually inclusive activities that facilitate the flow of design information (cladding product model) between business and project partners.
- Other issues central to achieving the vision of CIM working practice (for example, investing in adequate ICT infrastructure (hardware/software), changing the inherent culture and attitudes associated with current practice, and commercial constraints) have been discussed at sector level elsewhere hence deliberately omitted in this report.

### Benefits to WBP Facade Engineering Group

- The activity briefing sheets will assist the Group to manage the execution of the various activities involved in a project delivery process. They are designed to provide guidance and requisite information relating to the task being undertaken, and structured to enable the activity doer to capture useful information and feedback to the Group's technical documentation, for example master specification. Links to WBP QMS Intranet-based forms and procedures provide pointers to relevant QA requirements. A similar tool is currently being deployed in WBP Structures team as agreed by WBP directors on the basis of work reported here.
- The process maps add value to the Group's practice by capturing the 'as-is' facade package delivery process. Once benchmarked against suitable and appropriate performance metrics, continuous improvement regime could be instigated through monitoring, measuring, and evaluating the efficiency and effectiveness of the current delivery process. The maps help to prompt new thinking about how work is or should be done. They are also well suited for communicating, co-ordinating and integrating the Group's activities with those of project delivery chain partners.
- A spin-off benefit is satisfying the requirements of ISO9001 on process documentation. Aligned work is on going in WBP's QA Department.
• CIM implications on the facade engineering practice provide information and guidance for the Group in readiness for when the CIM working model becomes a reality.

**Recommendations**

Knowledgeable organisations utilise process maps and form the spine of activity briefing sheets. To adequately measure the benefits of the briefing sheets, particularly on entry-level staff, it is recommended that the sheets developed for the facades and structures disciplines be deployed at an appropriate scale that would permit the assessment and evaluation of the value-added on a quantitative or qualitative basis.

The integrated application of the principles of CIM working practice and CAM concept to facade work package delivery process will help facade delivery chain organisations streamline their external process and align their internal process respectively. Consequently, this will improve the efficiency and cost-effectiveness of the delivery process. Once a sector-agreed cladding product model is produced, it recommended that the Facades Group test and refine the concept of CAM, facilitated by the activity briefing sheets.