A REVIEW OF OBJECT ORIENTED CAD POTENTIAL FOR BUILDING INFORMATION MODELLING AND LIFE CYCLE MANAGEMENT

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Abstract. In many countries, the Architecture/Engineering/Consulting (AEC) industry is characterised by poor performance reflected in project delays and cost overruns. A contributor to the problem is the traditional approach to handling building information and its communication in life cycle management (LCM). Recent developments in Object Oriented Computer Aided Architectural Design (OO CAD) have provided the opportunity for improving building information modelling and its communication for more effective LCM. The aim of the paper is to review the potentials of OO CAD for building information modelling (BIM) and LCM. The paper reviews building information in the life cycle process, identifying the various actors and activities and the need for communication and information flow to support life cycle management. The paper also reviews the concept of OO CAD, highlighting its potential to improve building information and its flow and communication in life cycle management. The paper then goes on to review the potentials and limitations of OO CAD implementation in the AEC industry. The paper concludes by pointing out that the widespread adoption of OO CAD and the anticipated associated improvement in life cycle management will only be encouraged when the building industry is able to agree on a widely acceptable, interoperable standard for encoding building objects.

1. Introduction

Building facilities go through a complex evolutionary life cycle process, which starts from conception to design, construction, use and demolition (Blockley and Godfrey, 2000). The process involves many actors engaged in different activities that add value to buildings. The life cycle process from design to construction and delivery is project bound and takes place within the context of the AEC industry. In many countries, the AEC industry is characterized by poor performance manifested in inappropriate design solutions, construction delays and late delivery, cost overruns, and the general lack of adequate support and consideration for Life Cycle Management (LCM) (Day, 1992; Blockley and Godfrey, 2000). The situation is leading to disaffection by the main clients of the industry, building owners and developers. Industry initiatives such as quality assurance, quality management, total quality management, business process re-engineering, lean and agile, construction partnering, supply chain management, value management, all acknowledge the prevailing performance problems of the industry and the need and desire to address them (Blockley and Godfrey, 2000). There are several problems that combine to account for poor performance by the AEC industry. Among the problems is the lack of relationship and integration of activities across the industry, particularly between design, construction, and operations and management. This results in poor or inadequate communication in the building life cycle process. There is also a general lack of the recognition of interdependence among the players. In some cases, clashes of culture among the various actors preclude coordination and results in inappropriate assumptions or unjustified expectations of other actors in the life cycle process (Blockley and Godfrey, 2000). There is a general and growing recognition of the need to address the problems of the AEC industry and improve performance and the LCM of building facilities (Blockley and Godfrey, 2000). There is recognition that substantial opportunities could be created through a better development process that result in better design development and improves construction delivery and the operation of building facilities (Blockley and Godfrey, 2000). Industry wide integration of processes for better management of information and communication (Blockley and Godfrey, 2000) is the core focus in the search for improvement.

Buildings are the core focus of the AEC industry and building information is the critical element that binds the AEC industry in building projects and LCM. The main activity in the life cycle process is the processing of building information in order to ensure that a design intention becomes physical reality (Day, 1997). Building Information and its communication are therefore critical requirements of the building life cycle process. Efficient coordination and communication is needed to facilitate the flow of building information and the management of the process of development. The traditional approach to handling building information and communication in LCM accounts for much of the problems of the AEC industry. Activities in LCM tend to be fragmented with poor communication and information flow usually built on manual methods and techniques (Blockley and Godfrey, 2000; Day, 1997; Hegazy et al., 2001; Betts, Clark and Ofori, 1999). This result in building information conflicts, inconsistencies and mismatches that translates into higher construction cost, late delivery of facilities, and inadequate information for operational management of facilities (Hegazy et al, 2001; Chaaya and Jaafari, 2001). There is a desire within the industry to address the issue reflected in the amount of research work on it, for example Elzarka and Bell (1995), Brown et al (1995), Karim and Adeli (1999), Chaaya and Jafaari (2001), Hegazy e al (2001) and Erdener (2003). Much of the research work is focused on creating additional frameworks to improve the coordination of activities in LCM. The suggestions of additional frameworks appear to complicate an already complicated life cycle process and many reported initiatives are not usually backed by adequate consideration of their practical implication. There is a general recognition, however, that computers and information technology provide unique strategic opportunities that could be tapped for improvement across the AEC industry (Betts, Clark and Ofori, 1999:11; Brown et al, 1995). Object Oriented computer aided design (OO CAD) is one of the evolving Information technology products with potential to facilitate building information modelling and its flow and coordination across the AEC industry in LCM. OO CAD by streamlining building product information into a single database provides the potential to unify the focus of life cycle activities thereby enabling improvements in the overall process of management. The aim of the paper is to review the potentials of OO CAD for improving building information modelling and general performance in LCM. The focus of the paper is on project level coordination. The paper is divided into four main sections. The first section reviews the building information requirement in the building life cycle process. The second section reviews the potential of OO CAD in Building Information Modelling (BIM) and LCM, pointing out the specific product, process and industry wide advantages that could accrue from implementation. The third section reviews available OO CAD tools for modelling Building information and the functionalities they offer. The last section reviews the prospects and limitations of OO CAD adoption of in the AEC industry.

2. Building Information and the Life Cycle Process

Even though delivery methods may differ, almost all buildings go through a predictable life cycle process (Day, 1997). This process can be divided into 5 stages; feasibility studies and programming, design and construction documentation, construction and delivery, operations and maintenance and decommissioning. The principal actors and activities differ according to the different stages of the life cycle process. Figure 1 illustrates the various processes, actors and activities in the different stages of LCM.

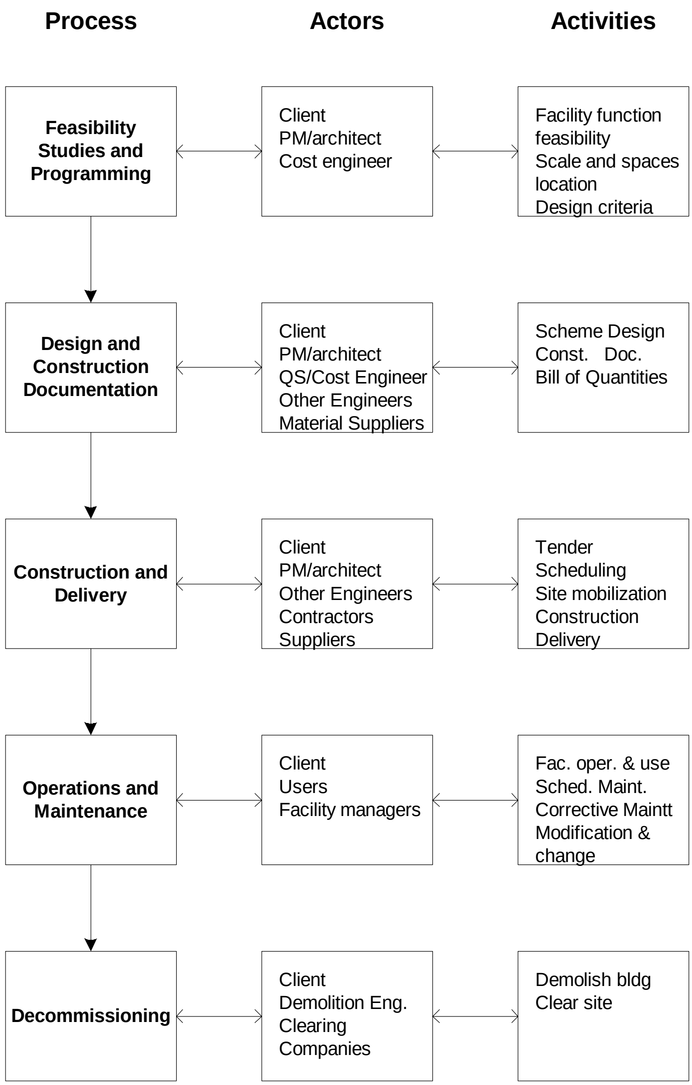

Figure1. The Building Life Cycle Process

Buildings information is the critical element that binds the AEC industry in building projects and LCM. The main activity in the life cycle process is the processing of building information in order to ensure that a design intention becomes physical reality that is deployed for use (Day, 1997). Building information generation, transmission and use varies according to the various stages of the life cycle process as is illustrated in Figure 2. In the feasibility stage, input is acquired from the analysis of existing facilities and previous experience to produce the facility program, cost estimates and facility location. Existing buildings along with their operations and maintenance history provide a database of information that can be mined to assess both design and systems performance. Unfortunately, as Bröchner (2003) observes, designers seldom return to assess the performance the buildings they are responsible for. There is also no established or poor framework for coordination in the industry between facilities operations and maintenance and the facilities planning and programming stage. Information from the feasibility and programming state is passed on to the design and documentation stage. It is at the design and documentation stage that fundamental decisions about the design of a building and the ways that project information is structured and presented are made (Day, 1997). The scheme design is first generated based on input from the feasibility stage. The scheme design is thereafter translated into detailed design and construction documents. The document, consisting of working drawings, specification, contract conditions and bill of quantities, provides information in sufficient detail to enable the pricing and construction of the work. The level of information varies depending on project and delivery method. There are several information and communications issues at this stage that affects the overall efficiency and effectiveness of LCM. The design process brings into play, many actors from different disciplines all with their working methods and ways of processing and presenting building information (Brown et al, 1995; Hegazy et al, 2001). The process generates new information, much of which is complex, fragmented, and has to be interpreted, mediated and acted upon by others (Brown et al, 1995; Chaaya and Jafaari, 2001). The evolutionary nature of the design process also means that changes and alterations are frequent, requiring effective communication and coordination among the various actors as well was with regulatory authorities and manufacturers to ensure the consistency and accuracy of building information (Hegazy et al, 2001; Day, 1997). Unfortunately manual methods of documentation and communication prevails in the process resulting in poorly coordinated documents with conflicts, inconsistencies and mismatches (Hegazy et al, 2001). There is also a need for active coordination in design with material manufacturers to facilitate design as well as the takeoff, procurement and the construction process (Elzarka and Bell, 1995). Such integration has been found to lead to significant cost reductions as well as reductions in document-processing cycle time.

Information from the design and documentation stage is packaged as a bid document to contractors who price and bid for a work. Once a contractor is selected, then "the information flow becomes increasingly intense as activity begins on site. Detailed matters have to be finalized, materials and fittings ordered and conflicts resolved while construction is proceeding. The flow of materials and operations has to be coordinated to ensure an efficient construction phase and the emerging building checked to ensure that quality standards are being achieved. The operative on site who finally has to fix a component in a particular place is just the final, but most visible, part of a complex information processing chain (Day, 1997). Efficiency in the construction stage is largely tied to the soundness of information from the design and documentation stage. Integration of design with activities of materials manufacturers and suppliers facilitates procurement activities in construction (Elzarka and Bell, 1995). The consequences of poor coordination in the design and documentation stage also becomes evident during construction, resulting in variation orders and contractual disputes that lead to cost overruns and to client dissatisfaction (Hegazy et al, 2001). This escalates with the complexity of a building project and the constraints on design time and cost.

Once the construction is finished, the facility is handed over to the client for deployment, and operations and maintenance. During the operations and maintenance stage, the focus of activity is getting people and processes deployed to a facility and ensuring that the facility remains in an operational state. The complexity of operations and maintenance depends on the size of the facility and the processes it is to hold (Erdener, 2003). To facilitate activities at this stage, a facility management information system is required. A building database is one of the critical components of the facility management information system. A building database shows the geometrical configuration of the building as well as systems, materials and technology of construction, and maintenance schedule. Where the facility information system also allows a facility database that includes space allocation, equipment inventory and other necessary facility management information to be tagged on, then building information systems can serve as the basis for developing a facility management database. The traditional approach to facilities operations and maintenance information generation as is illustrated by Osama Abudayyeh and Al-Battainneh (2003) in the example of bridge maintenance is through the preparation of as-built drawings that provide historical information relating to design and construction. There is however a lack of coordination in efforts to collect and store the necessary drawings creating room for improvement in the process. At the end of the lifespan of a building facility, it becomes scheduled for demolition and site clearance in preparation for the erection of a new facility in its place. At this stage, the principal building information requirements are of the materials and construction system. Knowledge of construction systems enables demolition experts to plan the demolition of the building while knowledge about materials helps in ensuring the removal of toxic and polluting materials before demolition.

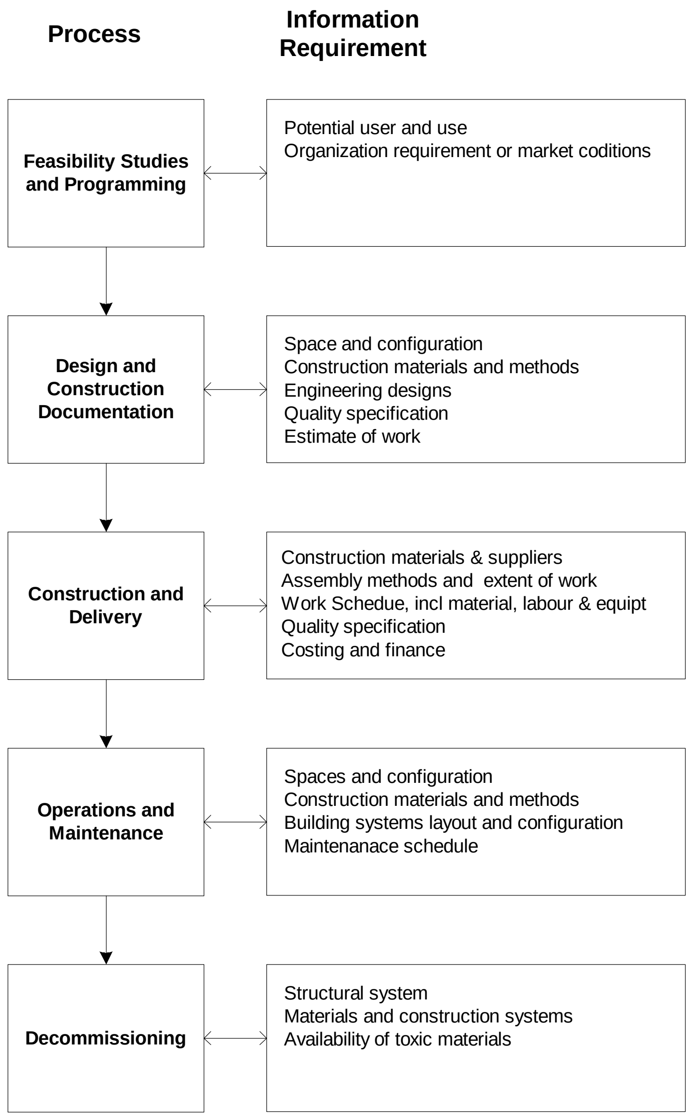

Figure 2. Building Information in Life Cycle Management

3. Potentials of OO CAD in BIM and LCM

Computers and information technology have played an increasing role in the AEC industry initially in design, but later in documentation and construction. Currently, computers and information technology are viewed as a way of addressing the communication problems of the industry and automating some parts of the design and construction process (Day, 1997). One of the technologies with the greatest potential is OO CAD. The concept of object oriented computing is based on the idea of electronic building objects. An electronic object represents a real world entity by encapsulating its characteristics, both data and function (Elzarka and Bell, 1995; Karim and Adeli, 1999; Brown et al, 1995). Data describes the state of the object while function describes the behaviour of the object under different conditions. The objects are smart and can communicate with each other. The benefit of the electronic object is proportional to the soundness of the data model of the objects (Elzarka, and Bell, 1995). In OO CAD building components are specified as electronic building objects. The Objects store 3D information - geometry, appearance, surface, material, quantity, construction and 2D information - such as plan representation, minimal space requirements, labels, etc, and property information - serial numbers, price, dealer information, cost and performance attributes, and other data base information. Objects describe real building component such as doors, windows, walls, roof, furniture, plumbing fixtures, HVAC system, structural elements, etc. The electronic building objects as representations of real life building components have parametric information that mirrors the behaviour and character of the components they represent. The objects behave smart and can easily be customized. The rich information about components embedded in electronic objects would be accessible by a wide variety of software applications and used throughout a building's life cycle without conversion or translation to other formats. Properties including shape, behaviour, performance data, and transport requirements, along with embedded links to relevant code requirement and test results, could all be included in an electronic object. An OO electronic door component, for example, will not only describe the physical attributes of the door needed for design by the CAD program, but also the cost, maintenance, supply and installation properties of the door for use in project costing and scheduling, and later for facilities management. Objects combine to form a complete model of the building which is much richer in information than 3-dimensional computer models. The adoption of OO CAD virtual modelling in the AEC industry has the potential to significantly impact the LCM process and the performance of the industry in three significant areas; the structuring and communication of building- i.e. product information, in facilitating processes in the AEC industry, and in improving the general performance of the AEC industry.

3.1. PRODUCT INFORMATION – THE VIRTUAL BUILDING MODEL

In OO CAD, the virtual building model is actually a database of information that tracks all the elements that make up the actual building (Figure 3). The virtual building model contains a great deal of information about the products that make the building as well as about the building itself. The Object-Oriented virtual model needs to be distinguished from generic 3D models. These are models based on a fundamental topology of lines, shapes and forms. Generic models are created using primitive and derivative geometric objects. The forms used in generic models have no relationship to the building elements they represent and modelling in this instance is of limited use, and is more or less a means for visualization. The OO CAD virtual building model as the electronic equivalent of the physical building provides comprehensive and consistent building information to support activities in LCM. The generation of all building information from an integrated model means that problems of poorly coordinated documents, conflicts and mismatches which characterise the traditional approach in the AEC industry is done away with. All information about the building is derived from the same source, is consistent and accurate. Also because building information is integrated in one database, it becomes easier to monitor and implement changes and alterations. This does away with the major source of the conflicts in building information documentation.

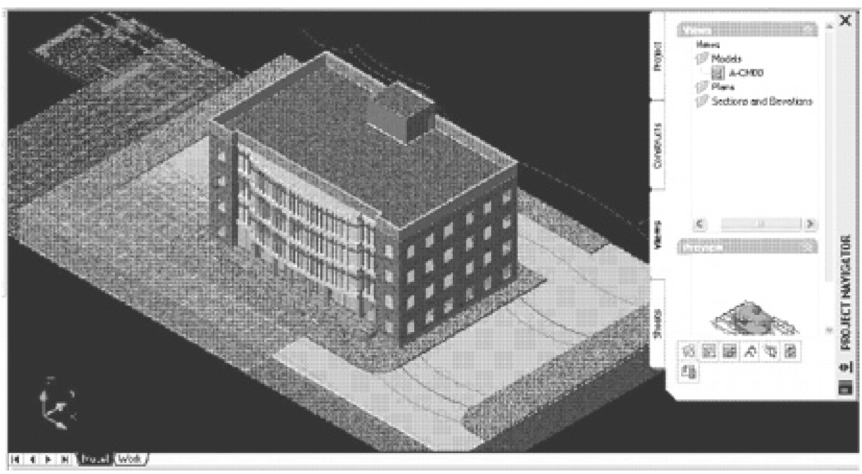

Figure 3. Example of an ADT Object Oriented Virtual Model

The virtual building model is also capable of supporting activities across the whole AEC industry and throughout the LCM process. Designers would all work on the same database, Objects used in the database would be supplied by industry or conform to established standards. Objects would embed information that supports all types of performance modelling and analysis for design purpose. Objects and the virtual model will embed information to support activities of all industry participants, from design to estimating, costing, scheduling, constructability analysis, and facilities management. Electronic objects in OO CAD, illustrated in Figure 5, would usually be supplied by building component manufacturers and suppliers. Electronic catalogues are easily integrated into design, as can be seen in Figure 6, enabling active coordination between building component supply and design and also improving the efficiency in procurement during construction. Design in OO CAD would usually be coordinated on a single virtual model.

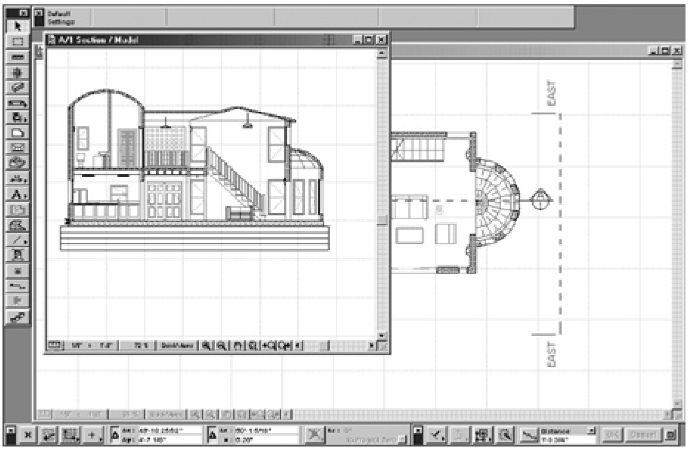

Figure 4. Conventional Drawings from an ArchiCAD Object Oriented Virtual Model

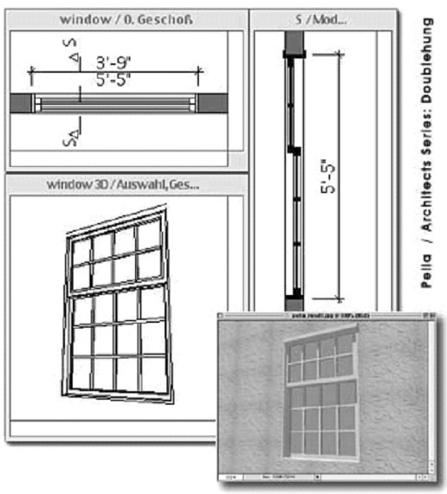

Figure 5. GDL building object supplied by Pella Corporation (www.pella.com)

The use of a single model reduces errors, improves coordination and the tracking of changes and the general accuracy of building information. This translates to a more efficient construction regime in later stages of the life cycle process and to time and cost savings. The OO CAD model also supports the generation of all kinds of report, including, doors and window schedules, illustrated in Figure 7, bill of materials and quantity, equipment and space inventory, etc. In supporting the generation of diverse information from the virtual model, the OO-Virtual model minimizes the time to prepare construction documents and therefore design and documentation cost in life cycle management.

At the construction stage, the potential for a more consistent and accurate building information coupled with coordination with building component manufacturers and suppliers means that pricing of contracts would be more accurate, change orders due to inconsistencies minimized and construction planing and scheduling much more efficient leading to better prospects of on-time and on-cost delivery. Construction can also be facilitated through improve project and construction planning. At the operation and management stage, the virtual building database provides a ready tool for use. With the addition of facility information it can be easily be transformed into a facility management information database to be used for long-term operational management. When the facility lifespan is over, it is also easier to plan for its demolition and removal because of the comprehensive building database available.

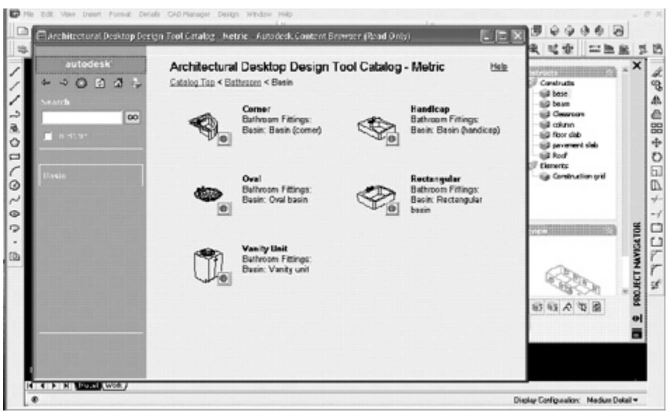

Figure 6. ADT Content Browser for Design objects

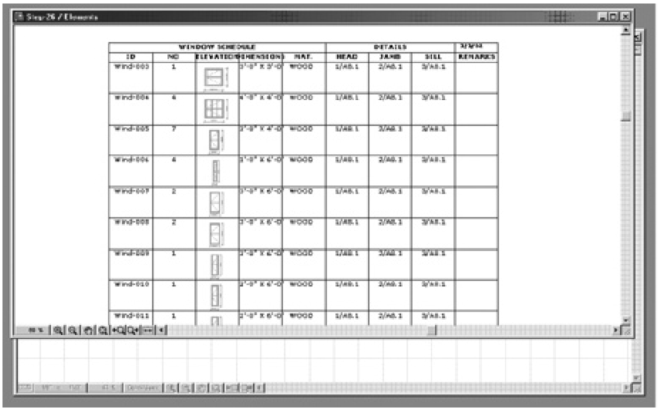

Figure 7. Door and Window Schedule from an ArchiCAD Object Oriented Model

3.2. FACILITATING PROCESSES ACROSS THE INDUSTRY

The implementation of OO CAD virtual modelling has the potential not only to impact on Building information and how it is handled in the AEC industry, but also on processes and operations of the industry. Virtual building modelling can become the basis for the integration of activities across the AEC industry. The development of a single project database that incorporates input from all design professionals, and provides the basis for quantifying and estimating building cost, project and construction planning may establish the framework for integration of activities and cultures and general coordination across the industry. Such integration would also be accompanied by improvements in communication and increased efficiency and effectiveness in handling conflicts all resulting in improved project performance.

3.3. IMPROVING GENERAL INDUSTRY PERFORMANCE

The widespread adoption of OO CAD virtual modelling across the AEC industry may in the long run lead to significant improvements in the performance of the industry. Virtual modelling will in general lead to more accurate building information in LCM, doing away with a major source of performance degradation in the industry. Accurate building information will mean a more streamlined and efficient delivery process. Cost overruns will be minimized and Scheduling and planning will be more accurate and information from construction will be used to support operations and management thereby enabling a global connection of the life cycle process and general improvement of LCM.

4. Available OO CAD Tools for Modeling Building Information

For OO CAD to gain widespread acceptance in the AEC industry, it is first necessary to have the necessary products in the market. It is therefore pertinent to ask whether there are OO CAD products to support the needs of the AEC industry. OO CAD systems have been in the AEC market for some time. Among the most prominent ones are Sonata, Reflex, ArchiCAD and Architectural Desktop (ADT) (Day, 1997). Some specific industries such as wood and metal fabrication also have OO programs designed to meet their specific needs. Among all the commercially available OO CAD programs, two appear to have taken a leadership position, ArchiCAD by Graphisoft and ADT by AutoDesk, and have been the driving force for the expansion of the implementation of OO Computing in LCM. They both provide parametric interfaces for virtual modeling supported by a library of generic and manufacturers building objects. ArchiCAD (www.graphisoft.com/products/archicad) is among the premier object oriented programs in the AEC market. It is built on a proprietary Geometric Description Language (GDL), though it is compatible with the International Alliance for Interoperability (IAI) Industry Foundation Classes (IFC) an industry wide standard for information interchange. Several Manufacturers support the GDL format and supply catalogues in GDL format. Several website are available supporting the GDL format. ArchiCAD as a building information authoring tool allows the creation of building databases that support design and documentation and provides for collaboration and coordination across disciplines and for easy alterations and modifications without comprising the integrity of the building database or the accuracy of project building information. To extend the functionality of ArchiCAD, Graphisoft is also marketing a 5-D Construction management solution that links 3-D modeling with scheduling and costing to support 5-D construction simulation (www.graphisoft.com/products/construction). The construction management system allows connectivity between accurate 3D construction models with Primavera Engineering and Construction and Primavera Contractor to enable the generation and analysis of scheduling alternatives. The system incorporates model based estimating functionality providing for the extraction of exact quantities and cost estimates. The systems is also supports procurement scheduling. The systems, in general, supports a vast range of activities integral to the AEC industry, including design, construction modeling, constructability analysis, and construction and procurement planning. To support the implementation of the construction management system, Graphisoft is promoting the emergence of a new AEC industry profession, "the construction modeler" who will be in charge of ensuring that every intended use of a model is considered when creating building elements.

ADT has developed through several release versions with the latest being ADT 2005. The program is built on AutoCAD and the proprietary dwg format, through it has more functionalities than AutoCAD. ADT uses ObjectARX technology to create intelligent architectural objects. These are kept in a content library of building objects and other modeling support tools. ADT supports design, documentation and schedule generation. The program has the capability of supporting all design professions and coordination can be undertaken using proprietary AutoDesk Building systems. Information could be shared through direct exports or through the use of proprietary DWF file sharing format. Data can also be exchanged with IFC-compatible applications using a plug-in. Developments in recent versions of the program have simplified the process of modeling.

5. Prospects and Limitations of OO CAD Implementation in LCM

What are the prospects for OO CAD adoption across the AEC industry and what forces may serve to limit such adoption? In terms of prospects for adoption, the two leading programs already have a wide installed base pointing to significant acceptance by the industry. Increase in future acceptance of OO CAD in the AEC industry will likely be propelled by three main factors. First is the general dissatisfaction in the industry and the search for initiatives to improve the performance (Betts and Clark, 1999:127-8). The need to improve integration of processes and activities throughout the industry will drive the adoption of information technology and OO computing will be one of the main beneficiaries. The second reason has to do with the need for industry wide initiatives that cuts across all segments. In this respects, OO CAD promises a means for bringing together members of the design team with suppliers to create better information flow to the construction process and to facility operation and management. In enabling such a broad connection across the industry, OO CAD fulfils the basic requirement for the adoption of any initiative. The third factor deals with developments in OO CAD. Improvements in the technology along with its growing adoption, and the increasing supply of electronic building objects by manufacturers point to a potential of wide adoption in the AEC industry in future. Already cases of coordination both in design and between design, materials suppliers and construction is being reported spurred by developments in computing technology (Bordenaro, 2003).

However just as there are forces which may encourage its adoption, there are also many forces that appear set to work against the adoption of OO CAD in LCM. One of these is the fragmented nature of the industry and the independent approach to addressing issues of project information. While construction engineers are busy looking for better ways to communicate through project schedule and information exchange, architects and design professionals are also approaching the same issue from a design perspective and facility managers from a facility management perspective. With such diverse perspectives and investment in different initiatives, it is going to be very difficult to accept and promote an industry wide initiative. Another problem has to do with the unique characteristics of buildings, the major focus in LCM. Each building is unique in its own instance, and construction technology has to cope with different types of special conditions. Building components and construction system also vary widely between localities. This means that for OO CAD program to be widely acceptable they have to be able to meet the needs of all anticipated conditions in building design. The ability to produce software that can respond to varying needs of users and design conditions will determine the willingness to adopt OO CAD.

Another limiting factor is technological. In an ideal environment, one would construct a three-dimensional computer model of a building which contained an accurate representation of every important component and material, including attribute data on physical properties and cost. This model could then be used to simulate the construction process and thus many of the problems which currently have to be dealt with on site could be resolved during design. As all the drawings would be views of this single model they would be automatically coordinated and if a component such as a window were moved there would not be the traditional problem of ensuring that every drawing which contained the window was changed accordingly (Day, 1997). Such a model will however raise a number of problems. The first is that it would contain a huge amount of data even for a small building and would create problems of data management. The second issue relates to the ownership and security of the information in the building database. Traditionally, the architect maintains the copyright to his drawing. Conflicts over ownership of data and fear over data security would all limit the adoption of OO CAD (Betts and Clark, 1999). There is also the issue of familiarity with the technology. While architects are currently rapidly embracing OO CAD, the other disciplines in the industry are not eager to adopt it. Adopting it for them might mean investment in training and in equipment changeover, which would limit enthusiasm. Finally, there is also the issue of data standards and interoperability. Due to the complex nature of the networks that contribute to a construction project, standards remain a key issue. The lack of a critical mass to impose standards has resulted in parties being unwilling to make technological advances, especially with respect to communication technologies (Betts and Clark, 1999; Laiserin, 2002).

6. Conclusion

The paper examines the potential of object oriented CAD for building information modelling and life cycle management of building facilities. The emphasis of the paper is on project level coordination. The paper reviewed building information in the life cycle process, the potentials of OO CAD in LCM, available OO CAD tools and adoption prospects. From the paper, it is evident that traditional LCM is characterised by coordination and integration problems which translate to higher project cost and late delivery. The fundamental problem of the life cycle process lies in the lack of effective frameworks for communication and the flow of information. Any initiative aimed at improving the performance of the AEC industry must therefore embody the sharing of building information.

Computers and information technology offer unique opportunities for addressing the problems of the AEC industry in building LCM, and OO CAD is one of the technologies with significant potentials. Examination of the potentials of OO CAD shows that it can unify building information and provide a framework for the integration of activities, and coordination and communication across the AEC industry. There are, however, several significant factors that may work to limit the adoption and implementation of OO CAD. In general though, it appears that there is a single issue that may propel adoption irrespective of limiting factors and that is the availability of electronic objects. The widespread availability of building objects by component manufacturers may be the tipping balance in favour OO CAD implementation in the AEC industry. This would only happen, however, when the industry is able to agree on an acceptable interoperable standard for the encoding of building objects that meets the information and process requirements of all actors in the life cycle process.

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