POTENTIAL OF OBJECT ORIENTED CAD IN FACILITATING THE LIFE CYCLE MANAGEMENT OF BUILDING FACILITIES

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Abstract. Communication and information flow among the various actors and processes involved in the life of a building is a critical necessity for effective life cycle management. The traditional building delivery process has to a large extent resulted in poor communication and information flow and has limited the potential for effective life cycle management. Recent developments in Object Oriented Computer Aided Architectural Design (OO CAD) have provided the opportunity for improving information flow in the building process and for more effective life cycle management. The aim of the paper is to examine the potentials and realities of OO CAD in improving communication and management in the life cycle process. The paper reviews the building 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 information 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 & Godfrey, 2000:251). The process involves many actors engaged in different activities that add value to buildings. Information and communication are 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 designing and translating design ideas to physical reality that are deployed for use. The traditional approach to building delivery and life cycle management (LCM) within the Architecture/Engineering/Construction (AEC) industry lacks an integrating framework that coordinates activities by the various actors. Activities in LCM tend to, therefore, be fragmented with poor communication and information flow usually built on manual methods and techniques (Blockley & Godfrey, 2000:252; Day, 1997:77; Hegazy et al, 2001:322; Betts, Clark & Ofori, 1999:6). This results in building information conflicts, inconsistencies and mismatches that translates into higher construction cost, late delivery of facilities, inadequate information for operational management, and general dissatisfactions by owners of building facilities (Hegazy et al, 2001:322; Chaaya & Jaafari, 2001:49). There is a general desire to improve the performance of the AEC industry and this is manifested in the amount of research work on the issue, 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 an additional framework to improve the coordination of activities in LCM. The suggestions of additional frameworks appears, however, to complicate an already complicated life cycle process and many initiatives reported are not usually backed by adequate consideration of their practical implication. There is, however, a general recognition that computers and information technology provide unique strategic opportunities that could be tapped for improvement across the AEC industry (Betts, Clark & Ofori, 1999:11; Brown, 1995:328). Object Oriented computer aided design (OO CAD) is one of the evolving Information technology products with potential to facilitate building information 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 and realities of OO CAD in facilitating the improvement of information flow, communication and general coordination 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 life cycle process, highlighting the integral stages in the process, the actors and activities at each stage along with discussions of the nature of the industry and the unique product they create. The second section discusses building information flow and communication in the life cycle process, pointing out the stage wise interdependent nature of activities in the process. The third section reviews the concept of OO CAD and its potential to improve information flow and communication in the building life cycle process. The last section reviews the prospects and limitations in the adoption of OO CAD in the AEC industry.

2. The life Cycle of Building Facilities

Even though delivery methods may differ, almost all buildings go through a predictable life cycle process as illustrated in Figure 1 (Day, 1997:62). This process can be divided into 5 stages; feasibility studies and programming, design and construction documentation, construction and delivery, operations and maintenance and decommissioning, organized in a stage wise order. The principal actors and activities differ according to the different stages of the life cycle process. The feasibility and programming stage establishes the viability of the project, its function and required spaces and the scale of the facility. The principal actors at this stage include the client, the project manager and architect, cost engineer and other specialty supporting staff. The design and documentation stage focuses on the preparation of initial design schemes, its translation into a construction document and the preparation of a bill of quantity for the work. Major actors in the stages include the client, project manager, and building designers. The design process is a multi-disciplinary evolutionary activity, which can sharply be divided into architectural, engineering and other related design (Hegazy et al, 2001:322; Brown et al, 1995:336). The process is characterized by frequent changes creating the need for adequate coordination. The construction stage involves tendering, selection of contractor, project scheduling, site mobilization, procurement, construction, and delivery of the facility. Several actors are involved at this stage including the client, project manager, architect, cost engineers, other engineers, material and system suppliers, and contractors. Once the facility is finished and handed over to the client, it becomes ready for deployment and for facility operations and maintenance. Operations and maintenance entails ensuring a match between people, processes and facility and also undertaking all scheduled and corrective maintenance activities and modifications necessary to adapt the facility to people and process requirement of the organization. Ultimately, every facility gets to live out its life and has to be decommissioned. Such decommissioning usually involves demolition and clearing to prepare the ground for a new facility. The life cycle process up to construction and delivery is project bound and takes place within the context of the AEC industry.

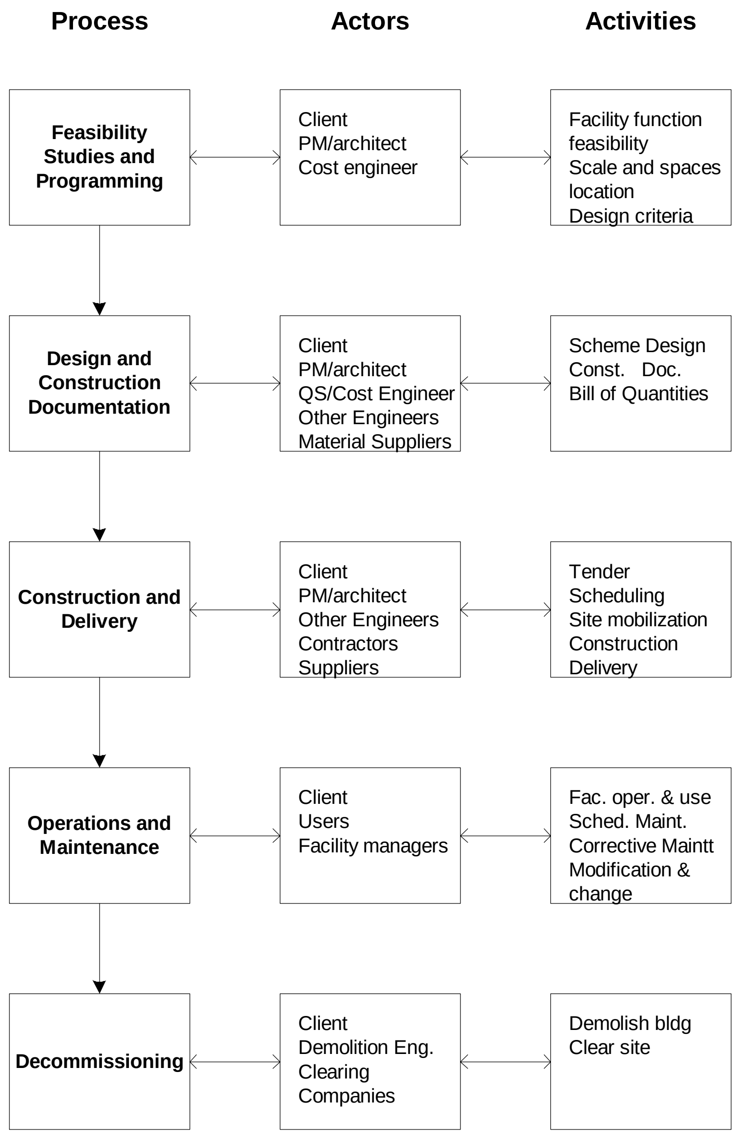

Figure1. The Building Life Cycle Process

The unique characteristics of the AEC industry play a significant role in the delivery and LCM of buildings. The industry is highly fragmented, being composed largely of many small organizations doing specialized activities with the discrete separation of the building lifecycle process into design, construction and operations and management. In the UK for example, 95%

of contractors employ less than 8 people while only about 1% of contractors employ more 35 people or more (Day, 1997:65). The same picture is reflected in the design organizations. Fragmentation is also aggravated by the temporary nature of project alliances whereby teams are assembled for particular projects and then disbanded after it is finished. In many countries, the AEC industry is also characterized by poor performance at a number of levels; from inappropriate design solutions to construction delays and cost overruns (Day, 1992:62; Blockley & Godfrey, 2000:5). Among the problems of the industry is the lack of relationship and integration of activities particularly between activities in design, construction, and operations and management, resulting in inadequate communication in the building life cycle process. There is also a general lack of the recognition of interdependence among the players and where process players have to work together, there are usually clashes of culture, whereby some process players make inappropriate assumptions or have unjustified expectations of others (Blockley & Godfrey, 2000:4). In the construction 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 problems of the industry and the need and desire to address them (Blockley & Godfrey, 2000:4). The problems have led to a growing recognition of the need for an industry wide multidisciplinary approach to improve the LCM of buildings (Blockley & Godfrey, 2000:5). There is a recognition that substantial opportunities could be created through a better development process that results in better design development, improve construction delivery and the operations of building facilities (Blockley & Godfrey, 2000:7). A suggested approach is through improving the integration of processes and teams, design, supply, construction and, operations and maintenance, for better management of information and communication (Blockley & Godfrey, 2000:12).

Buildings, which are the core product of the AEC industry and a focal point of any bid to improve the management of information and communication, also have their own unique characteristics (Day, 1997:62-64). Each building is unique and so design time is limited compared to other mass-produced goods. The design and construction team that produces building are usually constituted as a temporary coalition, thereby limiting the benefit of learning through experience. There are also a large number of construction systems that can be used for any building creating a certain degree of complexity. All buildings also contain a wide range of materials and construction systems and have unique properties with respect to use, plan arrangement, three-dimensional geometry and site. The combination of component, systems, and materials in a building assembled by an industry that is fragmented and works in temporary relationship creates an extremely complex system. Effective management becomes critical to the efficient functioning of the system. LCM provides the framework for conceptualization and evaluating the building process using life cycle objectives and concurrent engineering and construction approach (Chaaya and Jafaari, 2001:51). The goals of LCM are to increase building baseline value, improve its functionality, and generally contribute to the economic viability of owner organization while minimizing exposure to long-term liabilities (Chaaya & Jafaari, 2001:51).

3. Building Information in Life Cycle Management

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 that is deployed for use (Day, 1997:45). 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 (2003:20) 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, 1995:328; Hegazy et al, 2001:322). 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, 1995:328;

Chaaya and Jafaari, 2001:49). 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, 2001:322; Day, 1997:45). Unfortunately manual methods of documentation and communication prevails in the process resulting in poorly coordinated documents with conflicts, inconsistencies and mismatches (Hegazy et al 2001:322-4). 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 & Bell, 1995:438). 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 awork. 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, 1997:45)” 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 & Bell, 1995:438). 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, 2001:322). This escalates with the complexity of a building project and the constraints on design time and cost.

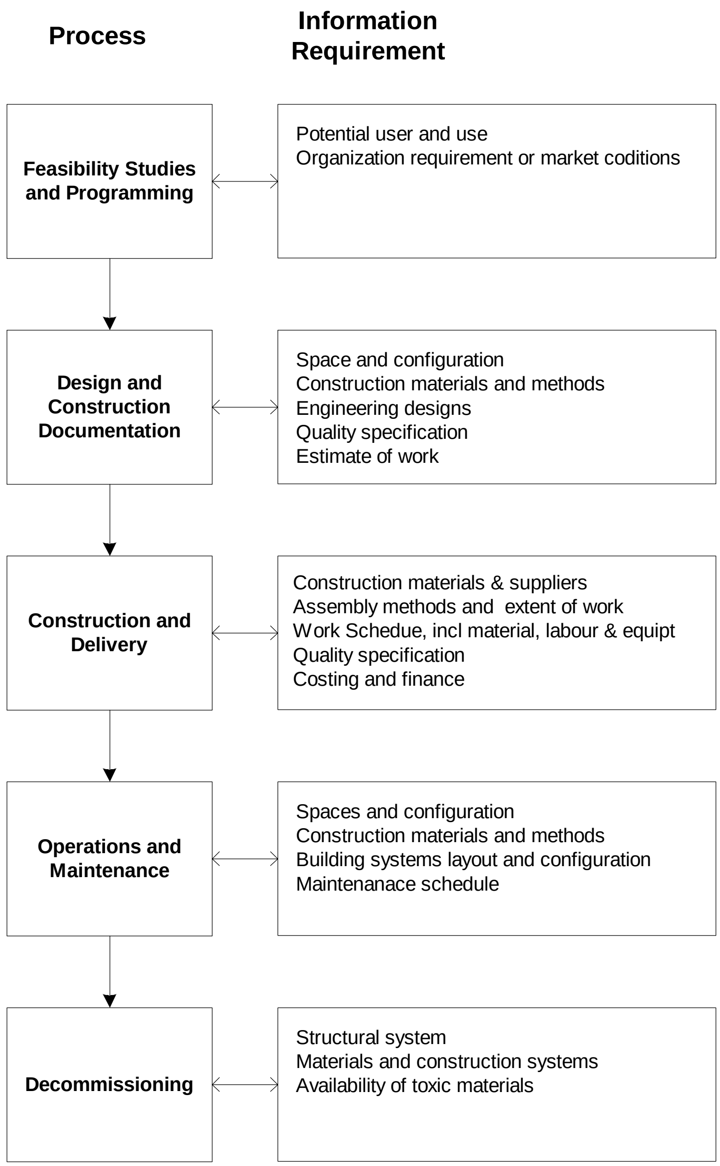

Figure 2. Building Information in Life Cycle Management

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, 2003:4). 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 (2003:105) 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.

4. Potentials of Object Oriented CAD in Life Cycle Management

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, 1997:14). 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 & Bell, 1995:439; Karim & Adeli, 1999:362; Brown et al, 1995:333). 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, & Bell, 1995:440). 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. Objects are generally of two kinds: general ones used to explore design and branded ones from manufacturers, which includes all variations of the objects and brand specific information. In objected oriented modelling, a virtual building model is actually a database of information that tracks all the elements that make up the building (Figure 3). Information contained in a virtual model include surface area and volume; thermal properties; room descriptions; specific product information; door, window and finish schedule; and more. The Object-Oriented virtual models need to be distinguished from generic virtual models. These are models based on a fundamental topology of lines, shapes and forms. Generic virtual buildings 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 simply a means for visualization. The lack of attribute properties means that the generic models have a limited capacity to support conventional forms of representation, making it is difficult to derive and coordinate conventional drawings from such models or to generation construction documents from them.

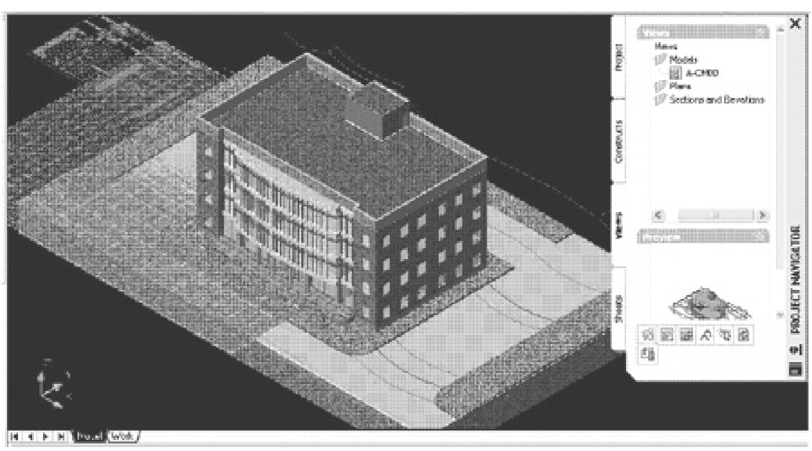

Figure 3. Example of an Object Oriented Virtual Model

The use of OOCAD has the potential to improve information and communication in the life cycle process with a consequent improvement in the general performance of the AEC industry. Object oriented models enable members of the AEC industry to work with familiar language of construction element representations as is illustrated in figure 4. It therefore eliminates the need for learning new communication conventions or procedures. The OO CAD model is a comprehensive database that is capable of supporting activities throughout the life cycle process as well as enabling communication and coordination among actors engaged in the process. 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. 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

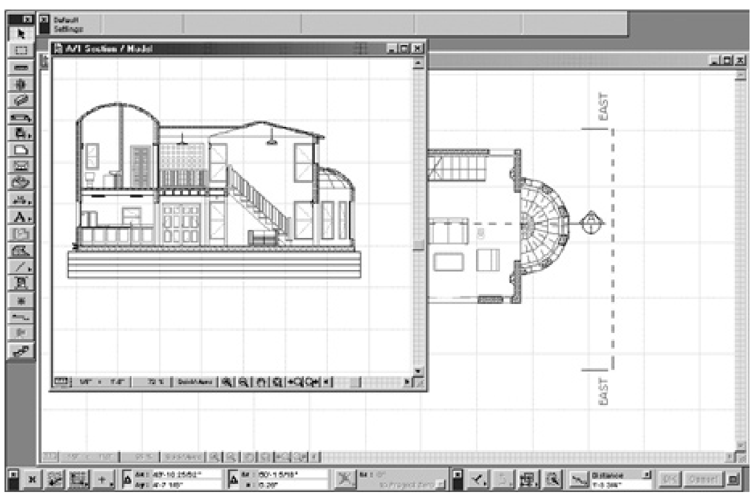

Figure 4. Conventional Drawings from an Object Oriented Virtual Model

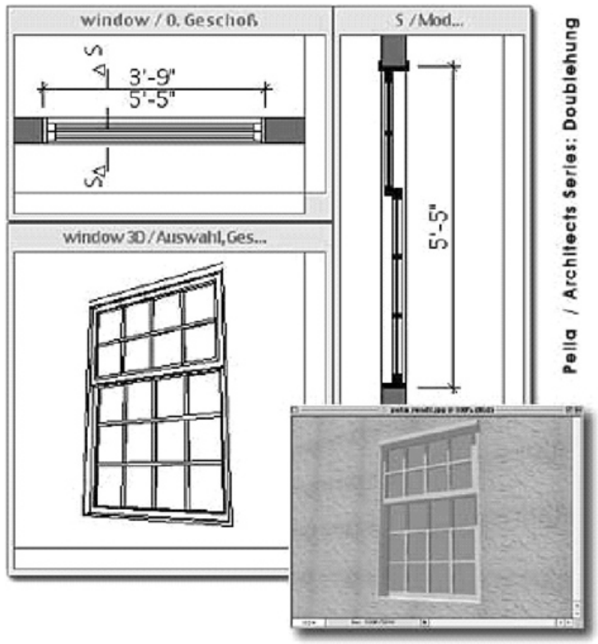

Figure 5. Example of a Manufacture Supplied Building Object

more efficient construction regime in later stages of the life cycle process and to time and cost savings. Mover, the virtual model is primed for all types of performance modelling, which is capable of improving design. 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.

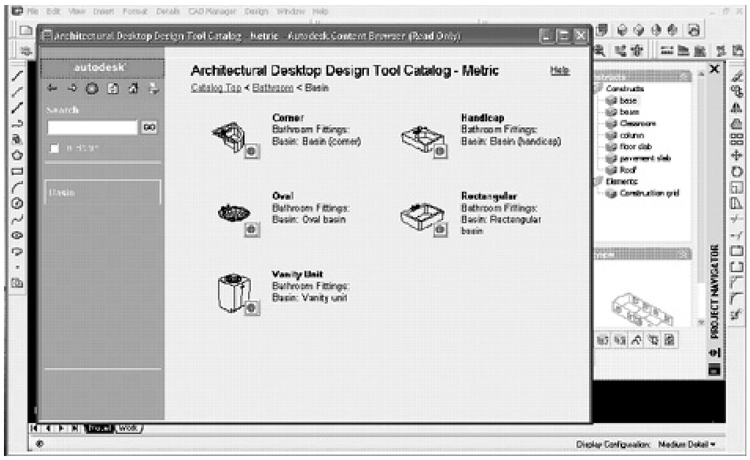

Figure 6. ADT Content Browser for Design objects

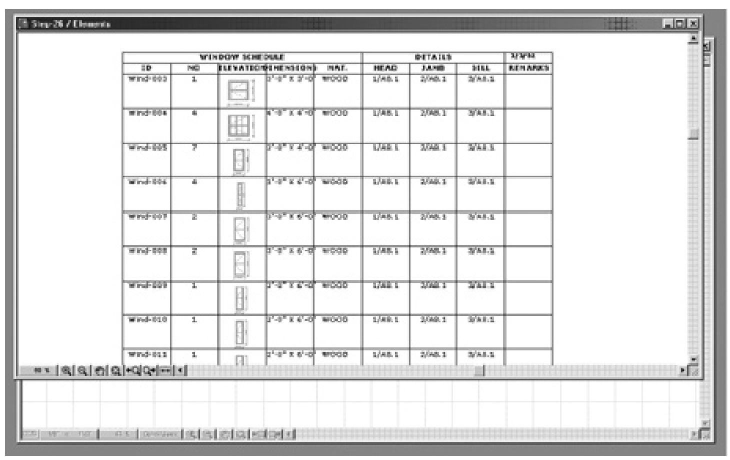

Figure 7. Door and Window Schedule from an Object Oriented Model

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. 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.

5. Prospects and limitations of Object Oriented CAD Implementation in Life Cycle Management

With the significant potential of OO CAD to improve information flow and communication and consequently building LCM, it then becomes necessary to review available software platforms for OO CAD and to examine prospects of adoption and the forces that may work against adoption and implementation. OO CAD systems have been in the AEC market for some time. Among the prominent ones are Sonata, Reflex, ArchiCAD and Architectural Desktop (ADT) (Day, 1997:53). Recently, however, two of these program ADT by AutoDesk and ArchiCAD by Graphisoft have occupied a prominent position in the market and have been the driving force for the expansion of the implementation of OO Computing in LCM. They both provide a parametric interface for virtual modeling supported by a library of generic and manufacturers building objects. 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 has a content library where building objects are stored and has a variety of tools that support the modeling of buildings as well as the extraction of different types of report from the virtual model. Developments in recent versions of the program have simplified the process of modeling. 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

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 & 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, 2003:151).

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. As earlier mention, 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, 1997:51). 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 & Clark, 1999:135). 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 & Clark, 1999:135; Laiserin, 2002:153).

6. Conclusion

The paper examines the potential of object oriented CAD in facilitating life cycle management of building facilities through improving building information flow and communication. The emphasis of the paper is on project level coordination. The paper reviewed the building LCM process, information requirement in LCM, and the potential of OO CAD in facilitating LCM. 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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