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Architecture, engineering, and construction informatics – An overview of the developments and future

T.V.S.R. Appa Rao

Considerable efforts are being made worldwide to develop an integrated environment for computer applications and information exchange in the architecture, engineering and construction (AEC) industry. The write-up presents a brief overview of the historical background of developments in computer applications for the development of AEC informatics.*

Keywords: *Computer applications, AEC informatics, information modelling, object oriented modelling.*

Architecture, Engineering and Construction (AEC) industry deals with many activities such as planning, estimation, structural analysis, design, detailing and drafting, construction planning and scheduling, materials procurement and management, fabrication, erection, quality control, cost control and management of human, material, equipment and financial resources any concerning construction projects. These activities involve large-scale use, generation, and exchange/sharing of textual and graphical data/information (in the form of engineering drawings and documents) among owners, architects, design engineers, builders, contractors, suppliers, financiers, and managers. Computer programs/software are being used extensively to find optimal solutions for different problems in design and construction and to create necessary data/information for the actual construction process. The project data/information needs to be exchanged/shared efficiently among the parties concerned to improve productivity. The term information used here implies/includes also the interpretation by human beings. Presently, data/information exchange is mostly in the form of documents/ reports (containing design data, schedules, etc.) and engineering drawings, either through paper or e-mail communication. It needs significant human interaction to interpret and transfer data/ information from one party/ application to the other involving considerable delays and possible errors. Therefore, vigorous efforts are being made worldwide to develop models for creating an integrated environment for computer applications and information exchange in the AEC industry. The importance of such efforts can be seen from the findings in the report, based on a study sponsored by National Institute of Standards (NIST), which estimated the cost of inadequate interoperability in the U.S. capital facilities industry to be US $15.8 billion per year[1]. This emphasises the need for development of appropriate and efficient information modelling, storage and exchange methods, which may be termed as 'Architecture, Engineering, and Construction Informatics' (AECI). This write-up presents a brief overview of the historical background of developments in computer applications, present scenario and future directions for the development of AEC informatics. Information modelling principles and object-oriented approach for development of AEC informatics have been briefly dealt with in the paper keeping in mind the integration of all

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computer applications of the AEC industry. The scope of the paper has been limited to the technical aspects of design and construction, with the possibility to integrate with business process applications as well.

Nature of AEC information

Information concerning any construction project grows rapidly and undergoes changes from the initial phase of conceptual planning to the phase of its completion. The information about the constructed structure/facility also undergoes continuous change during its maintenance and the total life cycle. Information may consist of data about many aspects such as physical form, topology, location, ownership, appearance and the constituent materials besides the behavioural aspects such as the strength, serviceability and performance of the building/structure and the highlighted methods/decisions. Different items of information are inter-related. At the initial stages of any project, generally the architect generates a conceptual plan, keeping in mind the functional requirements, in the form of sketches/drawings and documents describing various features/aspects and preliminary estimates. This textual and graphical data forms the input for preliminary analysis and design, which produce more detailed data and other information. Decisions are made at every phase to freeze the information which forms the basis for the next phase. Detailed calculations and expert judgments are involved in finalising several aspects of detailed design, construction planning and scheduling. The transfer/exchange of information from one phase of activity to the next is traditionally done sequentially, which is time consuming. On the other hand, the present trend is to devise ways to carry out activities concurrently in different phases, which leads to fast track execution of projects. This requires an efficient way of exchange of information.

Application of 'Information and Communication Technologies' (ICT) in the construction industry poses more challenges than its use in the traditional manufacturing industries such as the automobile industry due to the fact that[2]:

(*i*) construction involves one-of-a-kind products such as buildings and bridges that are usually unique,

(*ii*) construction products are designed, built and maintained as a one-of-a-kind process,

(*iii*) each process is carried out by a one-of-a-kind team of investors, contractors and subcontractors, and

(*iv*) team members vary in size, budget and level of IT expertise and are typically small to medium enterprise.

Computer applications development – Historical background

Vigorous efforts have been made since 1960s and considerable progress has been achieved in the development of computer programs/software for solving complex problems of analysis and design relating to the disciplines of architecture, structural engineering and construction planning and management. These have been fragmented in nature solving specific problems and requiring different inputs, which are repetitive to a certain extent. Use of such fragmented applications results in loss of time and productivity. Efforts are being made to integrate the computer applications by transferring the data from one computer application to the other through the commonly-used file formats like DXF and IGES. However, this type of integration has its own limitations. Early efforts towards development of integrated application software systems for design and construction of structures/civil engineering facilities started around 1960s. End users started development of subsystems dovetailed to such integrated systems to suit for their own specific requirements/use. When the information technology on which these systems were based became obsolete, use of such systems has diminished. This underlined the fact that better ways of information modelling by using object-oriented technology and adopting standards for data/information representation and sharing/exchange would help in creating electronic information systems for computer integrated construction processes. Therefore, vigorous efforts have been made since 1980s to develop scientific and efficient methodologies for modelling and exchange of data/information[3,4,5].

Vigorous efforts are being made worldwide to develop models for creating an integrated environment for computer applications and information exchange in the AEC industry.

Present trends - Integration

Present efforts aim at integration of different computer applications by making use of object-oriented modelling and database technologies. The developments in AEC informatics are intended to serve mainly the need for:

(*i*) facilitating integration of different computer applications

(*ii*) providing access to updated information for each party/professional (with built-in security measures and access rights)

(*iii*) design collaboration and concurrent engineering

(*iv*) web-based and distributed information access

(*v*) 3-D visualisation and virtual reality applications besides production of engineering drawings and reports

(*vi*) archiving total life-cycle data/information about the structure/project.

Modelling and exchange of information catering to the above

needs obviously pose many challenges. It has to deal with large volume and different types of data and information which is dynamic in character. It may be noted here that design and construction processes (and also facility maintenance/management) involve large amount of document-based information besides model-based information. Efforts are being made to develop efficient methodologies to integrate model-based and document-based information.

The total information concerning any project is generally stored/exchanged in the form of textual documents, engineering drawings and information models consisting of databases, rulebases (based on expert knowledge) and procedures (used in computer applications). It may be noted here that engineering drawings can be derived from 3-D models represented in the form of databases. In the context of a construction project, information relating to materials, building components and the building/structure as a whole can be represented/ modelled in the form of databases. The databases may represent data about size/geometry, properties, suppliers, specifications, etc. of the concerned component/object/product. Rulebases contain the expert knowledge for decision making concerning specific problems/aspects of different phases of any project such as planning, design, and construction. The rulebases form a part of the expert systems (software) that are generally being used as independent applications. A wide variety of application software packages (both general purpose and special purpose) have been developed based on different procedures/methods for cost estimation, structural analysis and design, and construction scheduling, etc. Since 1990s, vigorous efforts are being made to develop object-oriented models which can provide an environment for integration of all information that can be represented in the form of databases, rules and procedures/methods[6,7]. The intrinsic advantage of extensibility of object-oriented modelling makes it ideally suited for developing integrated software applications.

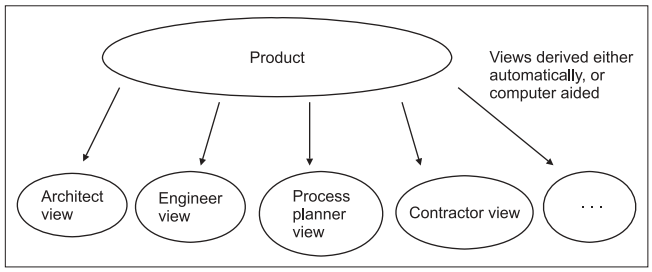

Fig 2 A view of the product model

Indian scenario

An assessment of the usage of ICT in India through a survey conducted by the author shows that the AEC industry makes use of computer programs for wide ranging applications in architectural planning, design, construction planning and scheduling, and for construction management functions. E-mail and computer networking facilities are being used for information exchange. The use of project websites and electronic trade in the industry is in the initial stages and it is not widespread. Databases are being created/used in electronic form only by a few organisations. However, use of computer applications is fragmented in nature and need for integrated information systems for efficient exchange of information is being felt.

Information is probably the most important 'construction material' and AEC industry requires a complete and adequate electronic project information system.

Information modelling – General

Information is probably the most important 'construction material' and it is clear that the architecture, engineering, and construction (or the AEC) industry requires a complete and adequate electronic project information system. The system should be able to support generation of output in traditional paper-based formats such as reports and engineering drawings besides catering to the needs of information of all the parties concerned throughout the life cycle of the project.

Information is being modelled/represented at different levels by domain experts and application software developers for implementation. The need for capturing information in a semantic (meaningful) way is well recognised. Information concerning any product or project/structure can be modelled as conceptual model and abstractions of object hierarchies by a domain expert independent of any database scheme/model that may be used for implementation. This is shown in *Fig* 1.

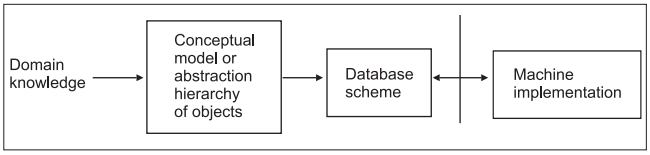

Fig 1 Modeling and implementation of information

Information models may deal with representation of information concerning the whole project/systems or a part (aspect) of the project/system. Information concerning any system may be represented with data/information concerning products, processes including rules and constraints, controls, and resources. Different types of models, such as reference models, core models and framework models have been proposed by different researches for representation of information concerning buildings and construction[8].

Product and process models

A method of addressing the issue of extracting different information from a single version of the data is to carefully design 'product models' and associated standards for storing and

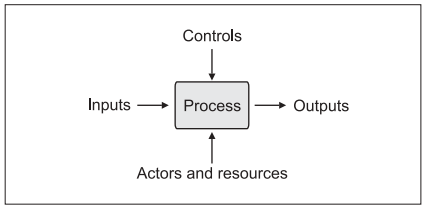

Fig 3 Basic structure of an activity in IDEF0

exchange of information. Product model may be defined as an information model that implicitly contains data regarding form, function and behaviour of a product and that can describe the product through its life cycle. The term product is used here to represent a building or any structure, or any of its components. *Fig* 2 gives an idea about the use/importance of product models for the AEC industry.

The idea to explicitly include behaviour in the product model is valid and can be realised with object-oriented technology. It is necessary to capture the product information in a semantic (meaningful) way. To represent total project information, basic entities for activities (or processes), resources and controls have also to be modelled. The four entities - product, process, resource and control – form the basic objectification of the 'Structured Analysis and Design Technique' (SADT) paradigm. IDEF0 is a method designed to model the decisions, actions and activities of an organisation or a system, and it was derived from SADT. The basic structure of information relating to any process can be represented as shown in *Fig* 3.

The four basic entities can be seen as the root entities of the complete set of information/applications in the building and construction area. The 'product' entity is the root for the traditional product model oriented type of applications. The 'process' entity is the root for all the activity-related software like design or construction. Resource is the root entity for resource-related software like site planning. And 'control' is the root entity for project management and decision support software.

Data exchange standards

Presently, there are two main standardisation efforts. These are the continuing development of Standard for the Exchange of Product Model Data (STEP) and the development of the Industry Foundation Classes (IFC) by the consortium: Industry Alliance for Interoperability (IAI)[3,5]. Object-oriented modelling (OOM) of information is being used in these efforts. Even though standardisation is an important aspect in data/information modelling, further discussion on developments in this area is outside the scope of this paper.

Object-oriented modelling and integrated environment for project information

The main challenge in modelling is the electronic representation of a structure/facility in a form capable of supporting all major activities throughout its life cycle. The new and advanced computer technologies based on object-oriented approach and associated database models, 3D/nD modelling, visualisation and animation, and web-based communications can be used to facilitate efficient representation, integration as well as exchange/communication of information[9]. *Fig* 4 shows a framework for such an integrated environment for construction information. Object-oriented development is a conceptual process independent of programming language until the final stages. One important advantage is that the objects are reusable within other software systems.

Considerable research and developmental efforts have been made since late 1980s to develop OO models of buildings and structures, and OO models of different processes of design, construction and project management. Concurrently, vigorous efforts have also been made for integration of computer applications spanning the domains of architecture, engineering and construction (AEC). Many major developmental projects were taken up during 1990s and they made use of object-oriented modelling and some of them adopted STEP/IFC standards for data exchange. These include projects such as CIMsteel (for computer integrated manufacturing in steel for building framed structures), COMBINE (for HVAC and building design), RATAS (for building design and construction management), OSCONCAD and WISPER (integrated environments for building, design and construction) and USACERL (integrated information model for design and construction). The salient features of these have been presented in Ref. No. 10. Many of these efforts concentrated on (object-oriented) modelling of product/project information/data. The CIMsteel project covered initially structural analysis and design and later extended to cover fabrication and erection. It is a very successful project in product and process modelling, and

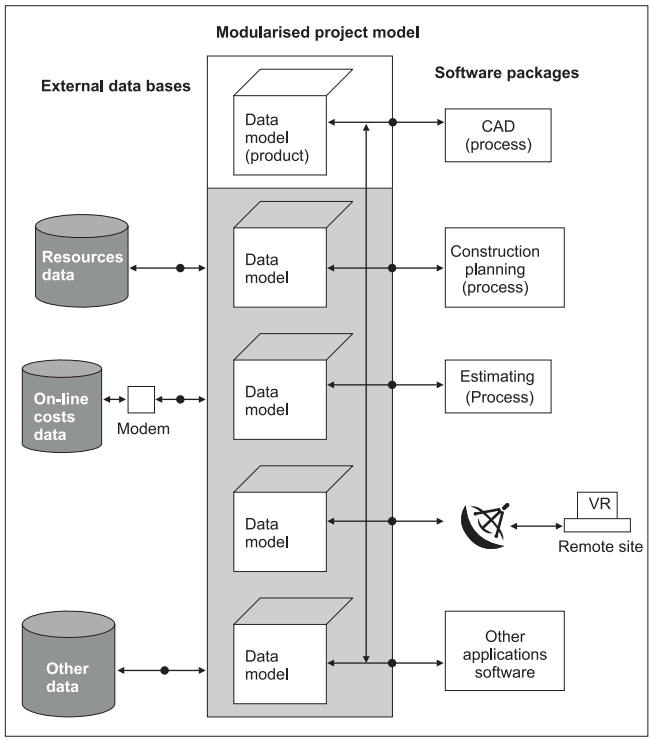

Fig 4 A framework for integrated construction information environment

data/information exchange for framed steel industrial buildings.

Future direction

Advancing the application of computers and information technology for the benefit of AEC industry has been a major thrust area of research and development worldwide. Efforts towards building product and process models, and industry data model standards will contribute to the development of AEC informatics. Development of innovative process design tools would allow users to interlink a wide variety of construction project information together with design and analysis tools such as 3D CAD. Increasingly, the internet will be used for distributed information systems and generic data exchange (using technologies like XML). Integration capabilities will improve in the future to develop, record, work with and communicate the overall body of project information. Developments in AEC informatics and increased use of internet will open new business opportunities including web-based services.

Concluding remarks

The importance and need for development of AEC informatics has been emphasised to improve the productivity of the AEC industry. Present trends in development of information modelling, data exchange standards and use of object oriented approach for facilitating integration of computer applications have been briefly presented. Future directions towards development and use of AEC informatics have been indicated. The purpose of the write-up would have been served if it triggers systematic efforts towards development of AEC informatics including development of standards for data/information exchange and integration of computer applications of the AEC industry in India.

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