A process model to support design and construction

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ABSTRACT: This research is focused on developing a highly detailed understanding of current organisational interactions and information flows leading to a definition of the process model for the environment into which information and communication technology (ICT) applications will be placed. The authors of this paper propose a theoretical process model and the associated detailed information structure which reflects the complexity of information, stakeholder interaction and intellectual property concerns which are currently seen in the construction industry. This is being developed and tested against a field study renovation project. The field study project identifies information flows and interactions between stakeholders such as designers, project managers, clients, contractors, subcontractors and suppliers. The process model which is being established shows very high levels of complexity in dependencies and interdependencies between implicit and explicit information within the project design and construction teams. Without an understanding of these detailed and complex process interactions, proposals for the application of ICT to the construction industry will not reflect the requirements of those for whom they are being developed.

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INTRODUCTION

Building production is one that involves a number of expert disciplines bringing specialised knowledge to a project and which work in an information rich environment. The development of data rich digital environments for the construction industry has been problematic despite the initial optimism when their application to design and construction was first proposed some 40 years ago. Many researchers have consistently expressed concerns about fragmentation and the lack of integration and interoperability in the construction industry and see the application of information technology (IT) as a possible means of addressing these. Despite its identified flaws and lack of uptake of IT applications, the industry is still able to produce very complex built structures. Although there has been much discussion about how to improve productivity, cost control and client satisfaction in the building industry, little progress appears to have been made. With industry fragmentation, support tools have become consultant specific to deal with the complexity and specialised nature of many of the design and construction processes. Other industries such as automotive, electronics, and shipbuilding have developed many industry wide processes to an advanced level. Reports such as Latham 1994, Egan 1998 and the Commonwealth of Australia 1999 have indicated that adopting manufacturing processes and their supporting technology will enable the construction industry to save up to forty percent of the total project cost (not to be confused with the net building cost).

Initiatives (IDEF0 1981; Froese 1995; IMI 1995; Poyet & Antipolis 1995; Aouad et al. 1998; Aouad et al. 1999; IAI 1999; Kazi et al. 2001; Tolman et al. 2001; Wilson et al. 2001; Gehre et al. 2002; Kazi 2002; Wix & Katranushkov 2002; Zarli et al. 2002) have presented generic processes and information transfer protocols to support business structure, design, construction and post completion stages at a macro level. It appears however that the defined inter-relationships between activities are not sufficiently applicable to industry to gain their strong interest and subsequent implementation. The Generic Design and Construction Process Protocol (IMI 1995) is perhaps the most detailed and thorough process model proposal and potentially influential for the Australian construction industry. On the other hand, like many other attempts, the process model presented is linear in its description of building process. There is evidence that these models acknowledge the inter-relationship between activities within the process. In spite of this, very little is known about who has what information, when, where, and in what form. Winch and Garr (2001) argue that the construction industry needs to develop a widely accepted ‘methodology for creating maps and protocols which can provide the baselines for shaping project-specific processes, and communicating to the client the merits of competing protocols’ (p. 528) rather than generic process protocols. Details of the background of this research has been discussed in (Pham & Dawson 2003, 2004).

1. THE THEORETICAL PROCESS MODEL

The use of a three dimensional description of a process model supporting digital environments has the potential to show high levels of complexity in dependencies and interdependencies between implicit and explicit information within the project design and construction teams. The authors propose a conceptual framework for the Distributed Information System (DIS) Network Model where the complexity of information and process interactions during design, construction and the building lifecycle may be defined (Figure 1).

1.1. Criteria for the DIS Network Model

From observation (see below) seven components have been identified as being critical for defining the theoretical process model. These are:
• Task: Work to be undertaken to complete a building element or achieve a particular Goal.
• Entity: End product resulting from the undertaking of a task or set of tasks (eg a building design or component).
• Nodes: The three defined nodes are Information node (eg data set), Stakeholder (or participant) node, and Task node.
• Process/Activities: Actions and/or support for actions (tools, equipment, space, information, time etc.) required to complete a task or achieve a Goal.
• Link: Relationship or connection between the nodes (eg a communication link between stakeholders or a critical path between tasks).
• Modes and States: Differing views of the network process model showing different relationships between the same or similar information.
• Time

The relationship between the components is described in Figure 1. The model may be scaled to allow the identification of supersets and subsets of related tasks, entities and nodes (see Figures 6 to 14). This provides for both a micro and macro view of the sequences, actions, requirements, links and responsibility for activities and tasks carried out during design and construction.

![Figure 1: Theoretical Distributed Information System Network Model](image1)

1.2. The implications of the process model as a 3D network system

This 3D network description allows project coordinators to identify within time, the sequence and responsibility of tasks and activities carried out by all project participants. The rich project information generated and delivered by all stakeholders is traceable through the links between the activities and processes carried out in the building lifecycle. The form described provides the scalability necessary to allow the complexity of industry interaction to be described in a network matrix. The 3D model representation deals with the complexity of the design and construction process in a Multi State approach. Hence, the same information structure may be captured and viewed in different states. Given the current building industry practices ‘a single repository that captures all the information used in building design, construction and operation is not likely to be achievable. Multiple models and repositories are not likely to disappear’ and ‘will be treated as a set of interconnected aspect models rather than a single integrated model’ (Eastman 1999). This is suggested in the theoretical model described.

2. DISTRIBUTED INFORMATION SYSTEM (DIS) VALIDATION

An investigation is currently being carried out into the design and construction processes of a renovation project of an existing 100 year old large warehouse building in Victoria, Australia. This field study is undertaking the mapping of information flows and organisational interactions in the project and is being conducted to test and validate the theoretical DIS model. All project participants such as designers, project managers, clients, contractors, subcontractors and suppliers have assisted in providing the necessary information (data sets, correspondence meeting minutes, requests for information, etc.) to support the research. The study commenced with the initial client briefing of the architects and will be completed on handover of the finished renovation. The interviews, analysis of the project documents and participation in project meetings facilitated the identification of the complex interactions of building information and processes. During the construction phase, site observations are identifying materials, items installed, and their location within the building. The study also includes the geometric relationship between the assembled components, their method of installation, spatial requirements for assembly and storage, and the tools and equipment used by the contractors. Interviews with all contractors were conducted to establish their complex organisational network and the interactions of information and processes, and links in their supply chain.

In the selected example, the design and assembly of the mechanical system has been selected to further validate (or otherwise) the theoretical model of the distributed information system structure. As highlighted, Figure 2 below shows the network of players directly involved during design of the hybrid displacement/ventilation passive ventilation system.

![Figure 2: Network of the Design Group](image2)

archi: Architect client: Client CM: Construction Manager MC: Mechanical Contractor ME: Mechanical Engineer PM: Project Manager

Figure 3: Network of the Information Generation and Distribution of Mechanical Design
The field study mapping showed that the interactions, communication, information flows (generation and distribution) and links between project participants during design was widespread over several players. The results showed a total of ten project participants were directly involved from project initiation to the tender phase. A total of thirty project participants were involved to achieve the realisation of the mechanical system design and assembly. Figure 3 above shows the interactions and information flows between the immediate players who are directly involved in the design of the sophisticated mechanical system. During the construction phase, the assembly of the mechanical system (T2 - Task 2) was selected and classified as a superset task. As shown highlighted, the task was broken down into sub-tasks (Figure 4).

To achieve realisation, the assembly process involved seven participants including the site foreman/leading hand as the coordinator of construction activities for the installation of the mechanical system. The construction site manager was also involved to coordinate other sub-trades who were directly involved in installation process. A network, including the supply chain for the mechanical services installation, was identified and is shown in Figure 5.

The breakdown of activities has been applied to the DIS network (see Figures 6 to 14). It shows all links between project participants and the relationships between the information generated and the processes undertaken. The detailed breakdown of the overall task into subsets has enabled the identification of who is responsible for different tasks, when they occur and the relationships between activities within each task. As identified, the evidence suggests that the interconnections, task dependencies and interdependencies, as well as flows of information become rich and highly complex.

2.1. The DIS Model Application
The significance of this model is in the ability to view the same information through various Modes and States. Two modes and five state views are evident. Modes 1 and 2 are related but are independent.
Mode 1: Task Specific
Mode 1 deals with task links and the information flows from one task to another (based on time). Hence, upon completion of one task, the next can proceed.
Mode 2: Stakeholder Specific
Mode 2 deals with the information generation and distribution between stakeholders. The state views are applied to differentiate the aggregation of tasks and stakeholders (modes).
State 0: Aggregated State View. See Figures 7, 10 and 13.
State 1: Communication Links - Modes 1 and 2. See Figures 8, 9, 11, 12 and 14.
State 2: Information Flows - Modes 1 and 2. See Figures 8, 9, 11, 12 and 14.

Figure 6 below shows some of the external task and organizational links directly involved in the installation of the new mechanical system. However, they are more involved indirectly through the Project Process Hierarchy of Responsibilities.

Figure 7: Detail Structure of Activities within Network Model of Task 2
This process model is to be viewed as a foundation model and as a new task set is required, it may be added to the process. As shown in Figure 7, numerous activities and sub-activities were required to be carried out to achieve the Goal; in this case the assembly of the mechanical services. A further sub task (Subtask 5) has been selected and detailed in Figures 10-12. This demonstrates the ability of the proposed DIS model to accommodate hierarchical task sets within an overall construction modelling program.

A breakdown at the Subsub task level will identify information such as the tools, equipment and spatial requirements that each trade needs to carry out their task efficiently and effectively. Similar mode and state views to those described in Figures 6 to 12 can also be developed at this level (see Figures 13 and 14 below).

**DISCUSSION**

The field study mapping showed that the task involved a high number of project participants which were required to be coordinated in the design and assembly process to allow the realisation of the sophisticated mechanical system. Several mismatches between the documented information and the actual construction were identified which caused some parts of the ductwork to be redesigned and remanufactured. As a result, labourers had to be coordinated to work on other tasks until the new parts were delivered. This could have been prevented if the existing information was analysed thoroughly during design. It is apparent that, to save costs, project participants often surveyed a portion of the existing building condition in great detail and assumed the rest of the building fabric was similar. Consequently, it affected the downstream players who presumed that the information was accurate. It was found that the integrity of the existing conditions survey by the project participants during design was not completely accurate and mismatches were resolved on site during construction. The assembly of the mechanical ductwork was designed with provisions (flexibility) for on-site modification. This seems to be an appropriate strategy in the current industry where collaboration and integration is rarely evident. The evidence suggests that the implications of dependencies and interdependencies tasks have a significant impact on a process and should be considered during design to minimise risks of delays and rework.

Although the expected outcome of the project was
explicitly explained in the architectural drawings, shop drawings and specifications, the extent of the work carried out by the contractor or individual construction workers was implied. This form of communication is based on the assumption, by the architect, that the downstream participant has appropriate knowledge to carry out the building task based on experience and precedence. Once the information is received by the contracting organisations, it was then interpreted, filtered and communicated verbally by the head subcontractors who were on-site during construction. This process allows the coordinator of a specific task (which may be a superset, sub set or sub-sub set of another task) to be in control of the interrelated activities and it also facilitates communication transfer at the coordinator’s level. The proposed DIS model facilitates description of these through a multi-state view of the interrelationships between tasks and stakeholders.

CONCLUSION

The initial information flow chart mapping showed that extremely high levels of complexity in dependencies and interdependencies exist between implicit and explicit information. The level of complexity of communication of the design and construction process is significantly more complex than that reflected in commonly accepted architectural documents. The detailed case study mapping has allowed researchers at Deakin University to construct a network to describe the sequence and responsibility of activities during design and construction. By identifying all nodes and links embedded in the network model, the complexity of task, information and stakeholder interactions can be described but requires a multi-state a process model.

The next phase of this research will involve the structuring of the results obtained from the field study. Further analysis of the project data from initial design to construction will enable the Distributed Information System Model to be further refined to reflect the information flows and knowledge system in current industry practice.

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REFERENCES
