

LIFE CYCLE APPROACH TO REQUIREMENTS INFORMATION MANAGEMENT IN CONSTRUCTION PROJECTS: STATE-OF-THE-ART AND FUTURE TRENDS

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Changes in client requirements are most frequent in construction and are known to contribute to budget over-runs and late delivery of projects. Such changes need to be managed adequately to enhance visibility, traceability and linked to the original requirements and communication with all stakeholders throughout the lifecycle of a facility. Traditionally, requirements management has principally been focused at the early stages of the construction process where elicited client requirements information is used as the basis for design and does not extend to the later phases. A life cycle approach is important because client requirements often change dramatically over a facility's life. This evolution needs to be understood, for example, particularly if the facility is to be refurbished or adapted for uses other than those for which it was originally designed. This paper presents an empirical study to highlight the current state of managing clients' requirements and to propose the need for a lifecycle approach to requirements information management in construction projects. An ethnographic study was conducted to examine the requirements management process based on participatory observations of construction project meetings and interviews with project managers. The study also details the state-of-the-art of requirements management by presenting a qualitative review of literature on this topic. This review includes industries other than construction. The paper concludes that currently, with no lifecycle insight, very few informal schemes detail the management of requirements beyond the design process into the later stages of the project. It proposes that the management of requirements should extend beyond elicitation and documentation and requires an approach that will enable changeability and impact analysis, accessibility, traceability and communication to all stakeholders.

Keywords: construction project, information management, life cycle, requirements management, traceability

INTRODUCTION

The Architecture, Engineering and Construction (AEC) Industry is one of the largest and most diverse commercial industries. The industry develops most of its products and services through integrated project teams which can be spread over several geographical locations. History has shown that engineering and development such as Aerospace, Software and Construction projects are frequently late, over budget and suffer from poor workmanship and materials with conflicts and litigations. Many factors are associated to this with a major cause being lack of proper brief or requirements management (Davis and Zweig, 2000, Fernie *et al.*, 2003, Morris and Hough, 1987). Briefing, which is one of the earliest phases of any construction

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project, is mostly concentrated at the early stages by client requirements elicitation, analysis, specification and validation. The outcome of briefing is a brief detailing the client requirements. However, the current trend is to look at briefing as an integrated part of the entire construction and project management processes and not just as part of an early stage (Worthington, 2000). This is important because client requirements often change dramatically over a facility's life. This evolution needs to be understood, for example, if the facility is to be refurbished or adapted for uses other than those for which it was originally designed.

Requirements Information needs to be managed across the entire life cycle and between all stakeholders. It is the project requirements that enable the development of the facilities between integrated project teams over several geographical locations. Lifecycle requirements management is emerging as a catalyst for the success of construction projects. There is considered to be a lack of system and methods to keep track of client requirements sufficiently and in a satisfactory way. Management of requirements is important for visibility, tracking and traceability which are crucial in change management circumstances. It can also facilitate better requirements exchange, collaboration and concurrent processes in an extended dynamic enterprise.

METHODOLOGY

Qualitative methods such as interviews and observations have been used in data collection. Participatory observations were conducted on a multi-million pound educational facility project over a period of four months. During this period, project meetings were organised to discuss the progress of the project attended by representatives of the client, contractor, architectural designer, structural engineers and external project consultants. Project meetings were attended, notes taken as the meeting progressed and audio records taken of the proceedings. This ensured that vital information was not lost as notes taking may not be sufficient enough to capture every detail. In order for accurate data to be collected, contributions were made by asking questions where a particular point was not clear. After each meeting, the notes taken were reviewed with the client project manager and external consultants. This assisted in triangulation of the data in order to reduce bias. All the recordings were transcribed immediately after the meetings while issues discussed were still fresh in the researcher's mind. Individual interviews were also conducted to discuss different issues on requirements elicitation, documentation, communication and change and traceability. Lifecycle management of the requirements was the focus of the interviews. Interviewees were selected based on individual experiences, expertise and role within the project. In total four separate individual interviews were conducted comprising: client project manager; contractor site manager; a senior manager from the external consultant; and senior expert from industry. A semi-structured interview was used with the help of an open ended questionnaire to guide the interview. The interviews were also audio recorded to facilitate the analysis of the data. Project related documents such as monthly progress reports, changes to project schedule and financials and requirements change request templates were collected and analysed.

RELATED WORK

Requirements - What are they?

In almost every aspect of life, there are requirements that will be defined in meeting certain conditions. We define what sort of cars we drive; we define our insurance needs; we define our accommodation requirements; we set educational standards for

students; and we place orders in restaurants. These are conditions that will be defined at the front-end of a service provision or project development. Such conditions will serve as guides on which the client/customer will measure how much of their (client's) desires have been met by the providers. These conditions specified by the client/customer become the requirements of a project or services.

From a general construction point-of-view, Kamara and Anumba (2000) state that “Client requirements can be described in terms of the objectives, needs, wishes and expectations of the client (i.e., the person or firm responsible for commissioning the design and construction of a facility)”. Kamara *et al.* (2002) further noted that “The ‘voice of the client’ (client requirements) includes the collective wishes, perspectives and expectations of the various components of the client body. These requirements describe the facility that will satisfy the client’s objectives (or business needs)”. According to the Office of Government Commerce, UK, “Requirements are capabilities and objectives to which any product or service must conform and are common to all development and other engineering activities.” Requirements may also be defined as a “description of a set of testable conditions applicable to products or processes” (Fiksel and Dunkle, 1992). Requirements are the statements of the client’s needs which are transformed into an architectural design and subsequently into a finished facility.

Requirements Management

Requirements management is a well researched and established area over the past decades and has been applied in major product development industries such as: Software Engineering, Manufacturing and Aerospace. Other industries have also applied the technique in their functions but not to the same scale. Its definition has been recognised by many experts and follows its applicability within an individual industry. It is an indispensable feature of every product development endeavour.

“Requirements management is the process of eliciting, documenting, organising, and tracking requirements and communicating this information across the various stakeholders and the project team” (Office of Government Commerce, UK). Fiksel and Dunkle (1992) defined requirements management as the process of creating, maintaining and testing requirements. The maintenance process includes dissemination. Testing the requirements is important to ascertain that they are valid and accurate for the purpose for which they were created. Fiksel and Hayes-Roth (1993) state that “Requirement management is the process of creating, disseminating, maintaining, and verifying requirements”. Requirements are open to change and their documentation should enable such changes to be made. As such, a variable that discusses modification must be added. Nuseibeh and Eaterbrook (2000) recognise this, stating that “Requirements management is the process of identifying stakeholders and their needs, and documenting them in a form that is amendable to analysis, communication and subsequent implementation”. One can observe that these definitions, despite coming from different industrial views have commonalities in them. It can be concluded that no matter what application industry, requirements management includes elicitation, documentation, communication, verification and managing change. Requirements management is a broad activity which houses different sub-activities across a product/facility’s life cycle of which communicating and maintaining changes to requirements are important. The mechanism of performing the management of requirements may be either manual, on an ad-hoc basis, or electronic. Traditionally this was done using manual forms but recent trends

show increasing interest in electronic and automated tools and techniques to ease the difficulties associated with maintaining information across the project. Such tools help in understanding the relationship and traceability links between requirements and their associated processes and products. It is important to comprehend that requirements management is not an activity that needs to be performed only at the early stages of a project but should continue throughout a project. Similar thoughts have been echoed by Ozkaya and Akin (2007) that “Requirements management is an inseparable part of design and has to be considered in correlation with form exploration, rather than as a front-end task. In any project, requirement elicitation and capture is among the front end activities between the client and designers. Once the requirements are captured, the brief document is used throughout the project. At each phase of the project, the requirements will have to be satisfied before advancement to another phase. This means managing the requirement variables, tracing changes and analysing the impact of those changes. Currently, no system exists to help integrate requirements management across all lifecycle phases of a construction project. Very few requirements management frameworks integrate into other phases. Most of these frameworks are simply to complement the design process.

Previous research has considered the development of models that can facilitate the process. The client requirements processing model (CRPM) was developed to help in the definition of client requirements and the incorporation of the different perspectives represented by the client body, by systematic mapping or translation of the requirements from the business terminology (“voice of the client”) into design terms (“voice of the designer”) to ensure requirements are presented in a solution-neutral format (Kamara *et al.*, 2002). CRPM has three stages. The last stage, translation of the requirements deals with transformation of clients requirements into design attributes. During all these stages, managing the elicited requirements is of great importance but it is apparent that the CRPM only feeds into the design phase of a construction project but doesn't continue throughout the later phases of a project.

However, we argue that requirements management process should be continued throughout the later phases of a construction project and not just to aid design. Managing requirements along all phases of a construction project does not only helps different teams perform their work efficiently but can contribute to the elimination of waste in design and construction. This is achieved because design re-works and construction defects are reduced with life cycle requirements management.

Research reveals that different media such as drawings, sketches, text, amongst others, have been used to manage and communicate requirements (Bouchlaghem, 2000). Computational tools have emerged that help to manage the different media. Most of these applications are general computer applications such as word processors, spreadsheets and databases. There are many disadvantages associated with such applications. There is a recognised need for more advanced tools. Ozkaya (2007) state, “Computational requirements management and engineering strategies need to evolve, along with algorithms to manipulate requirements for architectural design as well”. To address this problem, the Computational Hybrid Assistance for Requirements management (CHARM) process frame was developed. CHARM describes a process whereby a designer/architect needs to be aware of the requirements information of a given solution, or track emerging data by interacting with the computational system. All these different models and frameworks discussed have the potential to facilitate the requirement management processes within the construction industry. However, the extent at which this is done is limited compared

to the need for a lifecycle requirements management support system for construction projects.

Requirements documentation and communication

Elicited and captured requirements need to be documented and stored for future use across all phases of a project and throughout the lifecycle of a product/facility. Therefore there is the need to make sure that they are kept fully accessible. How requirements are to be communicated determines how they are represented and documented. Similarly, how they are elicited depends on the intended communication mechanism. Bouchlaghem *et al.* (2000) state that “The mechanism used for information capture in the briefing process is largely dependent on the processes undertaken to communicate that information”. Traditionally within the construction industry, requirements are commonly documented in static form: sketches and hardcopy. As information technology has developed and its popularity emerged, electronic forms of documentation have taken centre stage and word processing, spreadsheet packages and databases may be used. With technological advancement, research shows that communicating requirements electronically has gained momentum with the common use of e-mail and project extranets. This follows the briefing process as discussed earlier and serves to inform those involved in both design and construction after translation by the architectural designers into the specifications and drawings. It has been reported that requirements documents act as a carrier of information during design and production phases (Ryd, 2004). Different teams and stakeholders have an interest in specific requirements at different phases thus requiring information to be documented in a manner that is comprehensible to all concerned. Client requirements are detailed when the briefing process is completed. Smith *et al.* (1998) indicate that communicating requirements information to the design team in a significant manner is essential to ensure that requirements are taken into account. The writers contend that to guarantee that requirements information is taken into account in all project development activities across all phases, requirements should be made available to all stakeholders.

Requirements change and traceability

Client requirements are initially defined and elicited in the early stages of a project but clients constantly review and change their requirements of their facilities. The documented requirements therefore need to be modified and changed. It is generally accepted that lack of a capability to manage changing requirements is one of the major principal factors that contributes to delays and budget overruns of construction projects which as a result causes client dissatisfaction. Such changes result in impacts to both the cost and duration of a project and inevitably, demand consideration of who is accountable for the changes. “Requirements traceability refers to the ability to describe and follow the life of a requirement, in both a forwards and backwards directions (i.e. from its origins, through its development and specification, to its subsequent deployment and use, and through all periods of on-going refinement and iteration in any of these phases)” (Gotel and Finkelstein, 1993). Dick (2005) describes traceability from a software point of view as “documenting the relationships between layers of information - for instance, between systems requirements and software design”. IEEE standard (1984) state that “A software requirements specification is traceable if (i) the origin of each of its requirements is clear and if (ii) it facilitates the referencing of each requirement in future development or enhancement”. Traceability is therefore a key part of good requirements management. Han (2001) emphasises that traceability “facilitates analysis of how a new or changed requirement will affect the

system design and how an architectural design decision will impact on the system's functionality and quality". A change in client requirements should be traceable to the objectives of a project and be related to the lifecycle components of the building.

The demand for traceability management extends beyond design and flows into construction and post-construction phases thus taking a whole lifecycle dimension. However, according to Fernie *et al.* (2003), even though construction projects have change control procedures, they are not often sustained beyond handover of a building. Current document centric requirements management within construction makes it very difficult to manage traceability. "There are relatively few documented methods that provide traceability and ability to analyse change that extend into facilities management" (Fernie *et al.*, 2003). Traceability helps to support impact analysis of the change; identifying what has changed and what is affected enables evaluation of cost and time implications.

RESULTS FROM INDUSTRIAL OBSERVATIONS

The industrial study highlighted that different techniques are applied in requirements management in construction. Most of these take the traditional form with very few modernised methods applied. The observations confirmed that different stakeholders have an interest in the client's requirements at all phases of the construction project. All parties either in one way or the other participate in the process of managing requirements. Observations confirmed requirements documentation, communication, change and traceability form the basis of their management as discussed in current literature. However, the level at which this is done remains questionable if the efficiency and quality of current practice is taken into consideration. The process of managing the requirements involves eliciting, capturing and documenting them in a brief, a word document which details all the needs of the client which the project has to meet.

Documentation and communication

In the observed project, the greater part of the information generated after the production of the brief is generated during meetings transferred into word processed documents and sent in paper based form through the post to the contractor and architectural designer. From these documents 'hard copies', sketches and drawings are produced. One of the primary mechanisms for communicating requirements is through the use of e-mail messages with attachments of the brief documents. Drawings are then sent back to the client and contractor using the same mechanisms. Because drawings are most often 'hard copies', they are scanned before eventually being sent to a recipient.

In very few environments, are drawings uploaded to project extranets for access by all stakeholders. Even where the extranet exists, it was not commonly used for communicating and accessing documents. Instead, the design and construction teams rely on hard copies or e-mail messages with word attachments for sending and receiving such documentation. Teams are aware of security issues associated with sending word documents as attachments and want to ensure that the information provided is not changed at the time of receipt. Word documents are frequently converted to portable document format (PDF) before being sent to ensure no distortion or change to the information occurs. CDs, DVDs and other electronic storage devices have been used to store requirements documents and sent to relevant stakeholders. Using hardcopy to communicate requirements and their related information has a huge

negative impact on the effectiveness and progress of projects and their management. The observations revealed how external project managers frequently attend project meetings without bring with them change requests sent to them for approval. This affects all decisions to related requirements. During the observations, the importance of telephone communication whereby clients or contractors send requirements and query changes verbally was noted. This is seen as an easy way of communication requirements but undoubtedly is very ineffective in ensuring auditability, traceability and visibility of requirements.

Requirements change and traceability

Requirements are not static; they change several times during the life of a project. “As projects progress change to the stored information base that has been built up during the project are inevitable” (Bouchlaghem, 2000). Changes to client requirements may be initiated by different parties within the project e.g. a client may initiate a change in building space requirement, fittings and electric materials. Likewise, a contractor may initiate a change to in materials due to market availability. Whoever initiates a change, a change request form has to be filled and an approval process followed. This process is paper based and approval may take a long time before final approval is given. It was observed that different stakeholders attend different project meetings during which decisions are made on changes in requirements. Some interviewees noticed that in a more complex project such as Heathrow Airport Terminal 5, change requests required many different signatories for approval. Paper based forms of approval are frequently ineffective. Vast amounts of information on such decisions is kept in personal memories during the meetings and eventually lost over time. Procurements systems sometimes go wrong because they are not directly linked with the requirements. A situation was observed where a change to the requirements of a lift was made through e-mail but recordings of this could not be established. An order was placed for the lift based on the signed-off requirements. This was noticed only when the lift was invoiced. A new order detailing the new requirements had to be resent causing delay. Thus appropriate mechanisms are needed for the control of change and its subsequent communication.

Interviews with clients, contractors, and expert consultants, show that newly constructed buildings are typically handed over with operations and maintenance (OandM) manuals. These manuals detail the design of the building, the type of materials used, and how to maintain the building but not the client requirements. All interviewees agreed that although such manuals have proved to be very useful at handover they seldom cater for the life-cycle management of a building as they do not include the rationale for material selection.

ANALYSIS AND FUTURE TRENDS

Construction firms have been practicing requirements management since the inception of the industry. This involves the elicitation and management of requirements to make sure the constructed building fits for purpose. However, the level at which requirements are managed has to date largely only aided design development.

Traditional briefing has been applied to elicit client requirements. Once the brief document is produced and agreed upon, briefing stops and doesn't continue into other phases of the construction project. More recently the trend has been to look at briefing as a continuous process throughout a project. Similarly, if all parties, including contractors are to benefit from the project being completed within time and cost.

Requirements management should be considered as a lifecycle process. Figure 1 introduces Enterprise Requirements Information Management (eRIM) to support lifecycle requirements management. It is argued that managing requirements at each phase of a construction project will help to: (i) Reduce design rework due to lack of proper access and communication of requirements between designers and other parties (ii) Avoid or reduce construction defects (iii) Facilitate effective and efficient procurement of materials by linking procurement systems with requirements management systems (iv) Contribute to the successful operation, use, maintenance and refurbishment of buildings by providing facilities managers with adequate requirements of the building all through from project inception to completion (v) Enhance proper disposal of the building according to how it would be desired by the client and other requirements of environmental regulations. The analysis of the data revealed that after the detailed design is developed, requirements documentation is not usually applied in other phases and new and emerging requirements are not communicated to all other stakeholders. This creates an atmosphere where different teams will be working with different versions of requirements.

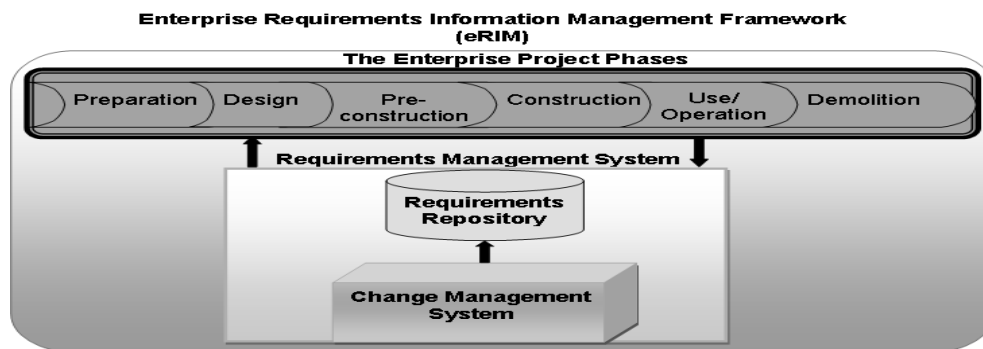


Fig: 1 Enterprise Requirements Information Management-Lifecycle Approach

This means any changes made affects previous requirements leading to wrong decisions made. The rationale for this is that the decisions behind the requirements is generally not captured and included in client requirements. We argue that decisions are an important part of requirements management and any process should include this in the documentation of the requirements. A database management could and should be used to house the requirements storage. This will enable an information centric approach instead of the conventional document centric approach to management of requirements. Change management is vital in any project as requirements keep changing and new ones emerge throughout the life of the project. Change control ensures that such changes are properly dealt with and are retained throughout the project. Current paper-based systems lack efficiency because of the number of people involved in the process and the iterations a request form goes through before approval. This involves human input and validation. Such tasks could be better handled with the use of process automation systems. Business process management, a modernised automation form of workflow systems could be a solution to this problem to better organise and manage the change process as its capabilities include visibility, traceability and auditability and augment the desires of a good requirements management.

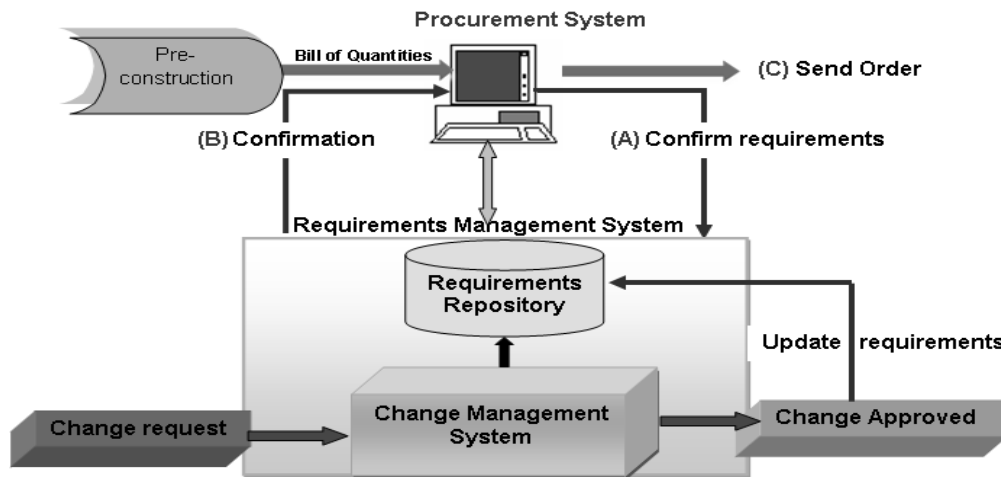


Fig 2: Integrated framework between requirements management system and Change Management and Procurement Systems

Enterprises such as construction rely heavily on separate applications for improved business performance and competitive advantage. Integrating the change management system with the requirements repository will help satisfy user demands for interoperability. In this way any approved requirement changes on the change management system would update automatically within the requirements repository. Many organisations have procurement systems for use during the pre-construction phase of a project. The procurement of all materials is based on requirements set out in the brief. It is common for incorrectly ordered materials to cause delays in project execution as observed in the lift episode. It would therefore be important to link the procurement system to the requirements management system to validate orders before they are placed. This has been demonstrated according to steps A, B and C in figure 2 where the requirements management system is integrated with a procurement system at the pre-construction phase within the enterprise.

DISCUSSION AND CONCLUSION

Analysis of the results show that managing and controlling changes and traceability have proved to be a difficult task in requirements management. In order to be in control of the change process efficiently, process automation using business process management (BPM) techniques are needed to reduce difficulty and inefficiency between teams. BPM can help the deployment of changes through a faster and more control change management process. Improvement of consistency of the process will be much easier and timely and will facilitate more frequent quality checks on the changes in individual requirements and provide assurance of a complete change process. One major advantage BPM supported change process can deliver is requirements traceability, visibility and auditability.

We have reviewed the state-of-the-art from the industrial observations and interviews and suggested future trends in requirements management in construction. An Enterprise Requirements Information Management (eRIM) has been proposed with a lifecycle approach to managing requirements across all phases of a construction project. eRIM will be developed with a centralised requirements management system that will integrate both the change process and project phases within the enterprise. It will help to enhance proper documentation and communication of the requirements information between all stakeholders of the project. Traceability will be supported between requirements which will facilitate impact analysis of the change.

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