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1. Introduction

The common operational practice of the construction industry is project-based. A general construction project goes through many phases from planning, cost estimation, bidding, contracting, architectural layout, detail design and engineering, to the actual building construction and the final project delivery stage. During a construction project, many decisions have to be made based on incomplete information, assumptions and personal experience of the construction professionals. Although the size, scope and complexity of construction projects may vary significantly, they tend to share one common element and that element is change.

In an EPSRC (Engineering and Physical Sciences Research Council, U.K.) report [1], it states that “More than a third of major clients are dissatisfied with contractors’ performance in keeping to the quoted price and to time, resolving defects, and delivering a final product of the required quality.” Specifically, “the clients’ dissatisfaction is due to the fact that over 50% of construction projects suffer from delays and over-spending, while more than 30% of the completed projects have quality defects. Furthermore, some 30% of construction is rework.”

“Disguise true facts at the beginning and issue change orders later” is not an unusual situation in the construction industry. According to a survey done by FMI (the management consulting firm headquartered in Denver) and CMAA (Construction Management Association of America) in 2004 [2], 84 percent of respondents said that they had encountered situations they considered unethical in their business dealings, while 61 percent of respondents said the industry was “tainted” by unethical acts. Owners were blamed for authorizing work and then trying not to pay for it. They were accused of passing off some of their responsibilities to others and playing games with payments, as well as still shopping for prices once all the bids were received. On the other hand, contractors were accused of over billing, front-end loading, bid shopping and playing change-order games. Architects and engineers were criticized for doing whatever was necessary to make their clients (the owners) happy, often at the expense of the contractor, and for knowingly issuing drawings and other bid documents that were defective and/or deficient.

Project changes and/or adjustments are inevitable as they are a fact of life at all stages of design and construction. Change management is considered an integral part of project management. It becomes very crucial to the success of construction projects.

2. The Fragmented Industry vs. Construction Project Management

Project management in construction faces some critical issues that are very different from other industrial sectors.

- Firstly, construction in Canada is an extremely fragmented industry. More than 95 percent of construction companies employ less than 10 employees. Except for general contractors, the capacity of most companies in the construction sector is also fragmented, for example, structure design and specialty trades. It is difficult to consider a

construction project as being under the total control of one organization (unlike the situation in other sectors). Architects, designers, engineers, contractors, suppliers and manufacturers (a multi-disciplinary multi-organizational team) must coordinate their efforts across different locations (multi-location), often using disparate technologies developed specifically for their professions (incompatible tools and information).

- Secondly, a construction project can be classified as “one-of-a-kind” production in manufacturing terms, or simply “one-off” projects. As a result, the relationships of different parties and the construction supply chains are project-based and short-term.
- Thirdly, the type of contract determines a project's organization, process, flows, documentation and even the responsibilities of individual parties. Since a product delivery system may vary from the traditional “design-bid-build” or “construction manager” to the recently popular “design-build”, the intricacy of project management is challenging. In addition, the different types of contract costing systems being used add a further complicated concern to construction project management.
- Lastly but more importantly, modern views of construction project management not only involve managing during the design, engineering and construction phases of the “product” – building, but also the life-cycle operation and maintenance management of the finished product.

The uniqueness of the construction industry may prevent the direct implementation of many methods and concepts developed for other industries such as manufacturing. This distinctiveness has provided interesting opportunities to researchers in the construction sector, to develop capabilities designed to sustain this major industry.

3. Classifications of construction changes

In construction projects, a change refers to an alteration or a modification to pre-existing conditions, assumptions or requirements. Changes in construction projects are very common and likely to occur from different sources, by various causes, at any stage of a project, and may have considerable negative impacts. A critical change may cause consequential delays in project schedule, re-estimation of work statement, and increased demands of equipment, materials, labour, and overtime. Changes, if not resolved through the change management process, can become a major source of contract disputes, and therefore a risk of project failure.

Classifications of changes, in general terms, apply to changes in the construction domain. For example, a change might be a “gradual change” or a “radical change”, depending on the degree of severity; or a change might be an “anticipated change” or an “emergent change”, depending on whether it is intended or not. Motawa et al. [3] summarize that:

> *Based on time, change could be anticipated or emergent, proactive or reactive, or pre-fixity or post-fixity. Based on need, change could be elective or required, discretionary or non-discretionary, or preferential or regulatory. Based on effect, change could be beneficial, neutral or disruptive.*

However, since the construction industry is project-based, it is best to discuss changes in the context of the typical stages/phases of a construction project. Table 1 summarizes stages, sources and impacts of construction changes.

Table 1: Summary of construction changes

Stage	Stakeholder	Types of changes	Impacts	Actions
Specification	Owner/Client/User or architect	Changes to requirements including specification, scope of projects, design brief, etc.; changes in codes and regulations	Changes in design and construction processes	Carefully provide detailed specification documents before bidding.
Design	Design/engineering Consultant	Incomplete/inconsistent drawings; design error/defect; design change; omissions of site conditions and buildability	Rework of design and drawing; rework in construction; change orders	Better control of design versions, drawings; site investigation; consider buildability in design
Construction	Contractor/sub-contractors	As-builts not in conformity with as-design; quality defect; unforeseen site conditions; value engineering; materials or equipment not available; inclement weather	Rework; change orders; changes in design	Quality control; site operational control; coordinated documents and drawings; daily logs

Owners need to change their original program when there are unanticipated changes in their thinking, their economics, or their circumstances. It would be inadvisable, imprudent, and inflexible to continue with all aspects of the proposed construction as is if it is physically possible and economically feasible to adjust the program to the changed conditions.

Architects find it necessary to recommend changes in the contract documents in response to unforeseen situations and to improve the project. If the architect becomes aware of errors in the contract documents, it would be unconscionable not to correct them

Contractors discover physical or economic situations, usually unanticipated, that would make it imprudent or impossible to follow the contract documents. Diverse conditions, unavailability of materials and equipment, and requirement changes are just a few of the factors that can cause design changes, which, in turn, can delay construction projects and increase costs. Contractors often make suggestions for changing the contract requirements. They may also offer recommendations in the interest of value engineering applications.

Other sources of change are unanticipated soil conditions, damage by weather conditions such as wind and rain, natural disasters such as earthquake, labour and material shortages, and fire and explosion. The construction contract allocates most of these risks between the owner and the contractor and some are covered by insurance.

The impact of changes to a construction project needs to be evaluated on a case-by-case basis in order to assist in the decision making process. Although some changes may bring in "benefits" to the stakeholders, especially to the owner in the long run, most changes, if not managed properly, will result in "negative" impacts, most likely time and cost overruns. In general, upper-stream changes have larger impacts. Lu and Issa [4] believe that the most frequent and costly changes are often related to design, such as design changes and design errors.

4. Rework, change order and Construction Change Directive (CCD)

Most researchers distinguish between three kinds of changes: change order, rework, and Construction Change Directive (CCD) [5][6].

No single party has an inherent right to change any of the terms and conditions of a validly executed contract unless the contract itself contains provisions that specifically allows for changes. A construction contract would be impractical if it did not allow the owner to make changes under certain circumstances during the course of construction. Thus, construction contracts generally contain a change order procedure.

Change order refers to changes that are generated by unanticipated causes, for example, scope changes from the owner, design / technological changes from the architect, and cost and/or time changes arising from supplier problems or unsatisfactory site conditions. This type of change has to be negotiated case by case and requires a common (documented) agreement between all involved parties. An effective process of dealing with change orders is not trivial in that it requires coordinating all aspects that relate to change orders, for example, documentation, drawing, process, flow, information, cost, schedule and personnel.

A Construction Change Directive (CCD) is issued by an owner or its designate requesting a change in the contract scope when there has been no agreement on cost. CCDs originate from disputed change orders and can become change orders again once the dispute is settled. The process of handling a CCD is simpler than that of change orders in that it directly starts from the implementation stage once the CCD is issued. Of course, adjustments and provisions must be addressed in the contract to accommodate the change works in CCD.

Rework refers to re-doing a process or activity that was incorrectly implemented in the first place and is generally caused by quality defects, variance, negligence, and poor design and on-site management. Rework is usually pure waste and should be avoided in most cases. A change, if determined by authorized parties as a rework, must be done without condition by the party at fault. The overspending of a rework can not be claimed, and moreover, subsequent costs caused by the rework might be charged as well, such as costs to the owner for late occupancy. Rework at the design stage is caused by incomplete or erroneous drawings and the lack of consideration of the "buildability" and site conditions. Since the design and construction processes are not changed, the only requirement for handling rework is to perform whatever correction activities are necessary to guarantee the conformance of the "as-built" to the "as designed". Although the process of reworks is simpler than that of change orders, the decision of rework is a difficult one since rework is normally accompanied by the demolition of what has already built. The cost of demolition and rebuild is very high and sometimes it is not caused by or not affordable to any one party. In most cases, reworks become change orders by minor

adjustments in design, construction processes or use of alternative materials as long as the baseline requirements can be still satisfied by the new alternative.

Figure 1 shows the relationship of change orders, reworks, and CCDs.

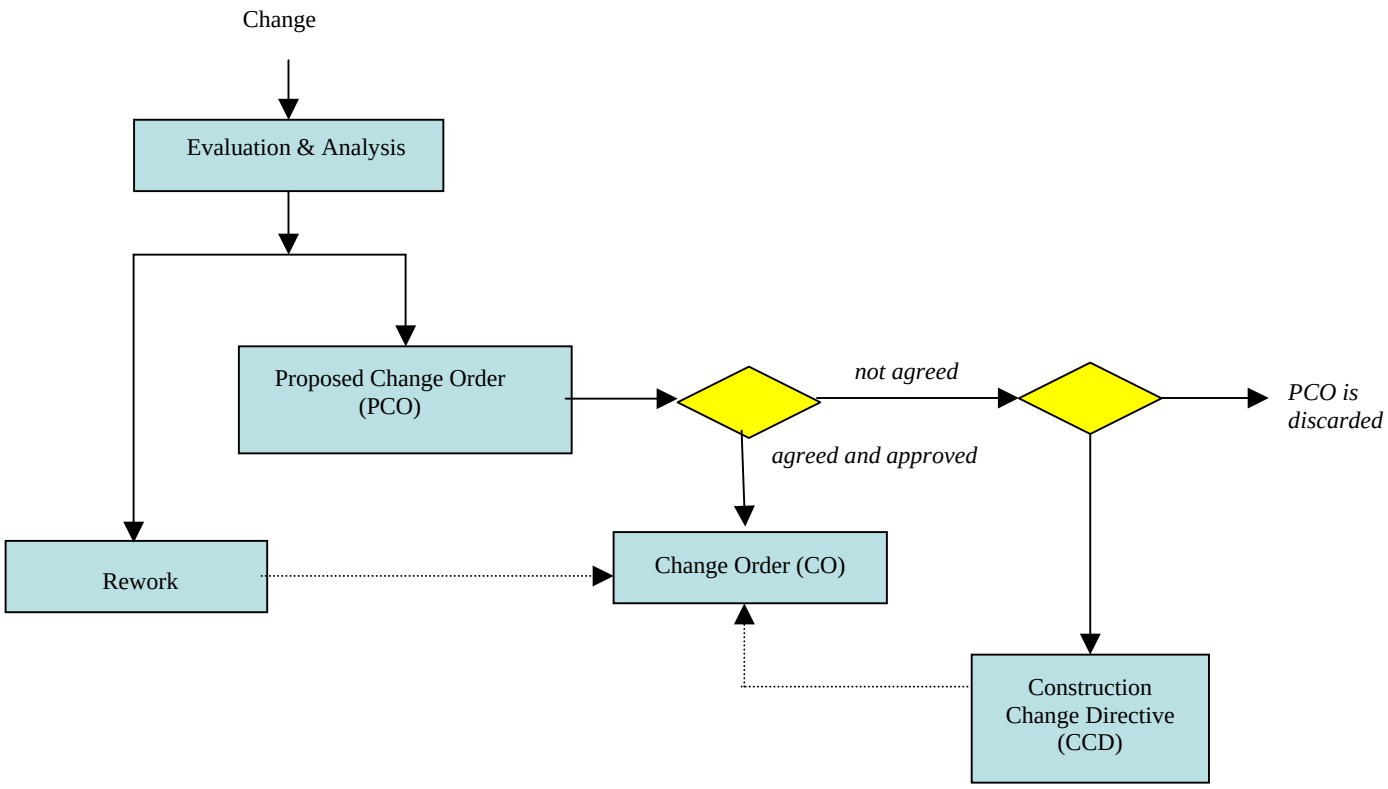

Figure 1: Change orders, reworks, and CCDs

5. Change order is a part of the contract

Change orders are common to most projects, and are very common with large projects. The owner or its delegated architect, engineer, or project manager has the authority to finalize change orders. Once a change order is submitted and approved, it generally serves to alter the original contract such that the change order now becomes part of the contract. The contractual nature of construction changes is a very distinguished feature of the construction industry.

A good construction contract includes provisions for dealing with changes to the project and a mechanism to settle disputes, such as arbitration. For a change to the project to be made smoothly, the procedures to make a change set forth in the contract between the owner and the contractor must be consistent with the change order process set forth in the contract between

the contractor and its subcontractors. Inconsistencies between the various contracts can lead to unintended consequences.

The concept of engineering change in manufacturing or other industries typically deals with any changes or inconsistencies between product design, engineering and manufacturing life-cycles. Engineering change management is thus focused on the co-ordination of product life-cycle model (PLM) and the enterprise management model in ERP, as shown in Figure 2. Since engineering change is not contractual, the impact of engineering changes stays generally within an organization and is well controlled via the vast adoption of integrated systems in manufacturing enterprises, such as CAD/CAE/CAPP, PLM, and ERP software tools. Construction changes are harder to control because of the fragmented nature of the industry and low investment and a lack of adoption of IT technologies.

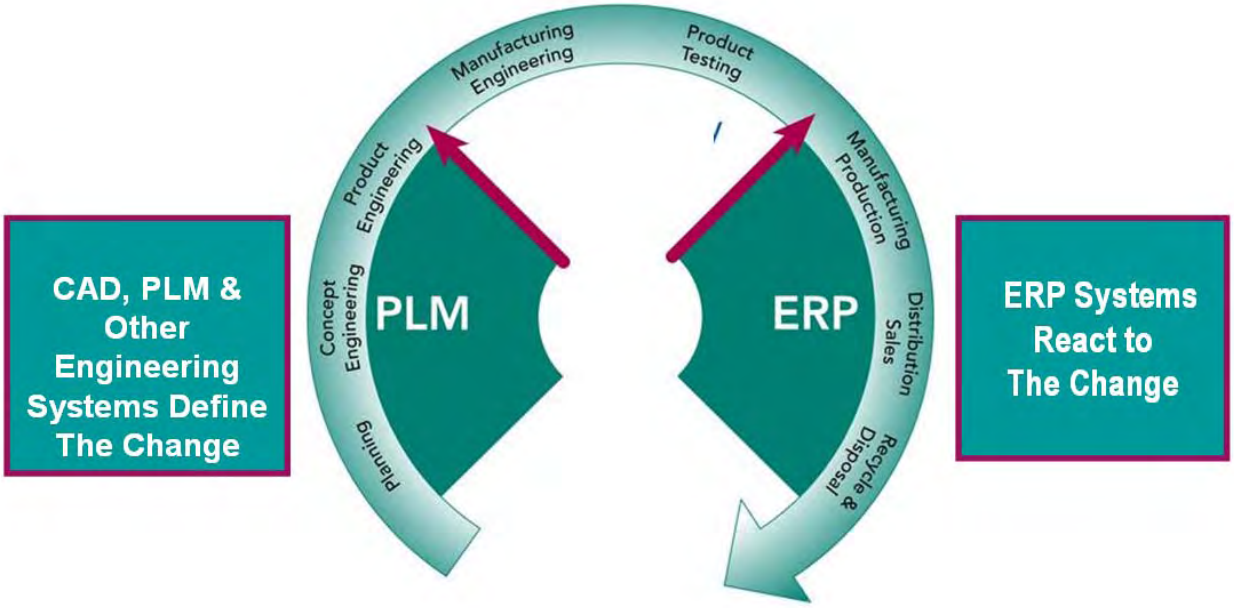

Figure 2: Engineering change in manufacturing [7]

A number of organizations and associations produce standard contract forms. These include the American Institute of Architects (AIA), the Association of General Contractors (AGC), the Construction Management Association of America, and in Canada, the Canadian Construction Association (CCA) and Canadian Construction Documents Committee (CCDC). A construction project management authority can choose to use any combination of these standard documents directly or develop their own documents as either modified standard documents or proprietary in-house contracts. As change orders form part of the contract, all of these standards have articles or clauses to obligate the change management procedure.

6. General change process model

Change management seeks to forecast possible changes; identify changes that have already occurred; plan preventive measures; and coordinate changes across the entire project [8]. Small reworks with minor impacts do not need to go through a formal change process. However,

changes with noticeable impact, either reworks or change orders, require following a formal process in change management.

We have developed a generic change process model consisting of five stages in a sequence: identify, evaluate & propose, approve, implement and review (Figure 3). The process model is based on a synthesis of the change process models reviewed in the literature and the characteristics of computational environments.

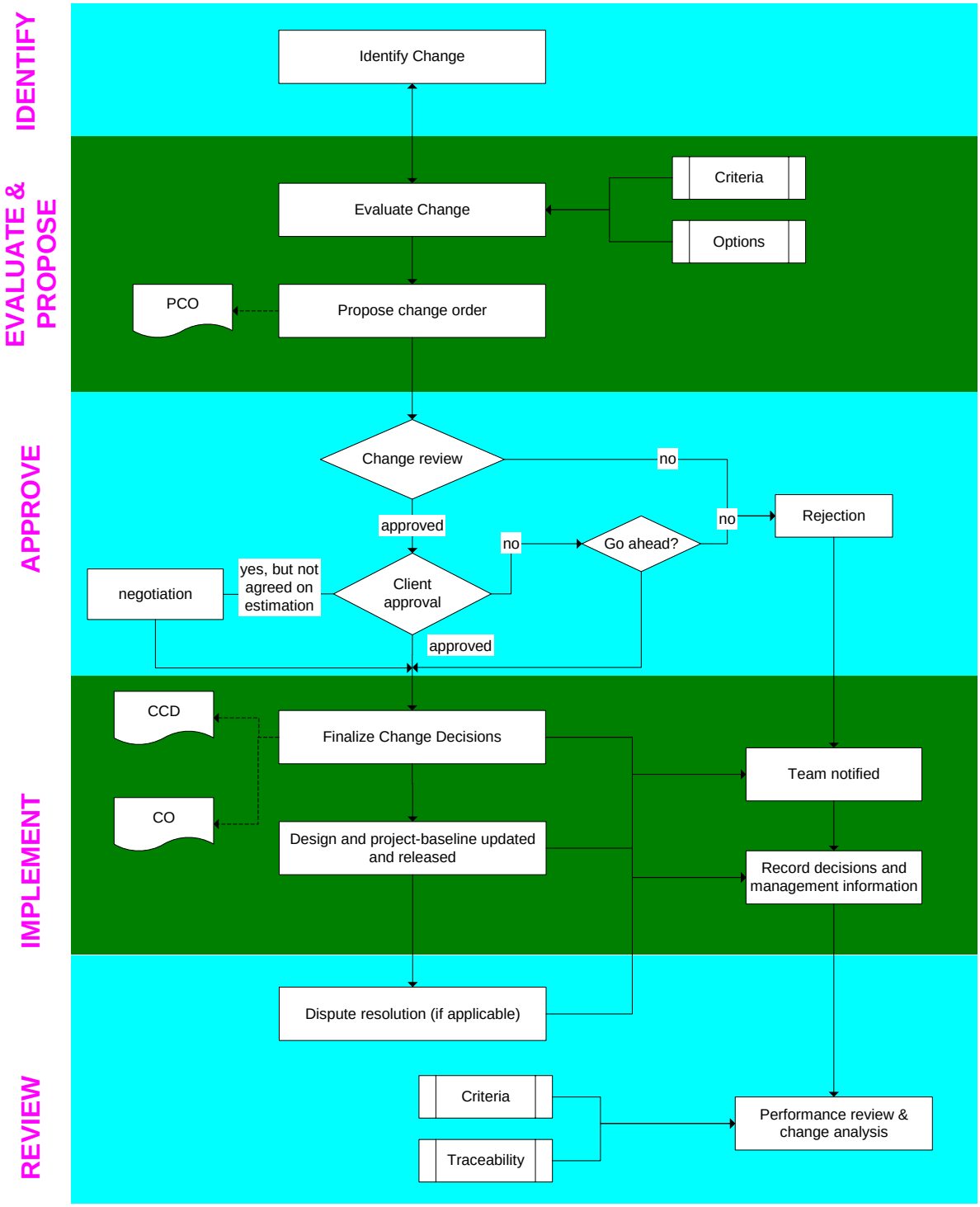

Figure 3: General change process model

6.1 Identify changes

There is a set of proactive rules defined to identify changes (including sources, causes, types, and possible actions of changes) during the duration of a construction project. This requires an effective change management system to properly build up the relationships of requirements, symptoms, malfunctions, and various aspects of changes.

It is common for a typical change management system to exclude the identification stage and start with the change evaluation and proposal processes. This is because the initiating role of a change is hard to be taken automatically by the system, or at the least a computational system is far less “smart” or “intelligent” than people thought. However, from academic or innovative points of view, the benefit of having an ‘identify’ stage is that when a project deviates from its anticipated behaviors, the system can proactively predict that possible changes might happen or are about to happen. Reaching the “intelligence” of such pro-activeness requires much R&D effort.

6.2 Evaluate and propose changes

Based on criteria and options, the evaluation module calculates all possible impacts that an identified change can have on other processes and team members, in terms of time and cost. Analysis and (if possible) optimization of change options is required for decision-making – whether to proceed with any of the change options or to undertake further investigation. The evaluation steps include options evaluation, impact assessment and optimization of change options and impacts. Different models and decision support systems can be used to facilitate the evaluation of changes that have already occurred or are about to occur. This stage requires heavy effort to model the intelligent behaviors involved in the decision making processes. The outcome of the evaluation is a proposal change order (PCO) which summarizes the change itself and the impacts of the change – a new updated action plan, cost, schedule, etc.

6.3 Approve changes

Each identified change needs to go through a formal approval process. There are a set of predefined approval processes for different types of changes and construction contracts. Firstly, all involved parties (except the client or its designee) must agree on the proposed change of work described in the PCO. This is done through a change review process. Next, the approval of the client is required for the PCO to be finalized. This may involve decision making on acceptance, improvement, or rejection of changes.

For instance, if the identified change is perceived to require a significant investment or if there are other options to replace it, the change can be rejected. If a change is approved, the corresponding additional work scope is introduced to that particular activity. A rejected change may either become a permanently rejected change or it might still be enforced by the owner in the form of a CCD even if the terms in it are not finally determined. A rejected change and its processes are recorded in the change management system as well so that it can be re-evaluated in the future when the change conditions are ready.

6.4 Implement changes

The change management process model requires all involved parties to keep records of all relevant information on change cases to build a case base for any future use. The implementation of changes mainly refers to the management and coordination of information, documents, design/drawings, and records are coordinated with the changes and their impacts. Unlike previous stages, no major decision is expected during the change implementation stage. An operational system is needed to make sure that all aspects are updated, all parties are notified, and all activities are carried out properly and coordinated well. Everything recorded is linked with each other and to the change cases as well in order to facilitate the change analysis procedures afterwards.

(ECR: engineering change request; ECO: engineering change order; OCM: order change management)

Figure 4: SAP ECM model [9]

6.5 Analyse changes

When dispute resolution is applicable, it requires the investigation of direct and indirect causes of change. In such a situation, the analysis of the effect of multiple change causes could be prepared. Change analysis and system performance is reviewed based on the data collected during the change implementation phase.

The process of engineering change management (ECM) is very similar to the general construction change model detailed in Figure 3 [9]. A comprehensive, flexible and workflow driven ECM is a centerpiece of the SAP PLM solution (Figure 4). However, this SAP module provides a change management solution for product engineering process only. Manufacturing processes are not considered in the loop of change.

7. Literature in construction change management

A large quantity of research in change management has been carried out in the generic project management domain. However, there is very limited research work addressing the change management issues specifically in the construction project management context.

- Sun et al. [10] designed a change management toolkit for construction projects that includes a change dependency framework, a change prediction tool, a workflow tool, and a knowledge management guide.
- Ipek and Ömer [11] investigate requirement-design relationships and enable traceable requirement in architectural design. They developed a prototype system called DesignTrack and used LEED requirements as a case study.
- Lee and Peña-Mora [12] proposed using system dynamics to build dynamic project models to assist planning and control of construction projects. This dynamic project model captures several non-value adding change iterations (rework cycles and managerial change cycles). The simulation is demonstrated using a case study in Road Bridge Construction, and many change option/policy implications are summarized based on this case study.
- Motawa et al. [3] presented some preliminary results on proactive change management through an integrated change management system composed of a fuzzy logic-based change prediction model and a system dynamics model based on the Dynamic Planning and control Methodology (DPM). These models were previously developed by the same group to evaluate the negative impacts of changes on construction performance. Their work also provides a good literature review on construction change management.

Apart from the project management domain, some other researchers have been trying to address change management issues in various other ways:

- 4D or 5D integration which integrates time and cost models in addition to 3D geometry models. In this way, changes can not only be controlled in the design and engineering stages of the whole construction process, but can also be controlled in the built environment lift-cycle to some extent. Jongeling and Olofsson [13] suggest that location based scheduling provides a promising alternative to activity-based planning approaches for planning of work-flow with 4D CAD. In this approach, work schedules are integrated with design models so that changes in design or during construction can be better coordinated. In the latest 5D technologies of Graphisoft [14], automation does not stop at design changes. ArchiCAD also automates and coordinates the creation of documents, schedules, bills of materials, and quantities estimates through its integrated “virtual building” model based on IFC’s BIM models. Working with “Building Information Modeling” means working directly on the design model in any project view – be it the plans, sections or even element schedules. All one needs to do is to perform one change in the design model at one place at one time and all the integrated project views will be updated automatically.
- Data sharing and interoperation. Bakis et al. [15] proposed an approach to model the complex interrelations of the different components in the various aspects of the design and the different versions of each component in order to maintain consistency in architectural design. When changes happen, the interrelation models help notification/propagation of version changes. They also suggest that the development of standard building models is essential to enable data sharing, exchange and change management at the design stage.

- Web-based integration and collaboration approaches. Lottaz et al. [16] proposed using constraint satisfaction techniques to express possibly large families of acceptable solutions in order to facilitate and abbreviate the collaboration and negotiation processes, ultimately to improve the change management and the productivity during phases of design and construction. By combining Web services and intelligent agents, collaborative workflow technologies can be used to handle dynamic and complex business processes on the Web and can be applied to construction project management systems for effective and flexible change management. We have done a comprehensive literature review of collaborative workflows in design and manufacturing integration [17].

8. Challenges and supporting technologies

Developing an effective construction change management system is a challenging task because, it requires an integrated solution for coordinating and re-organizing everything for the purpose of change management in question. An effective construction change management system has the following requirements:

- Consolidating all aspects of change information, including causes, symptoms, sources, impacts, actions, and processes of changes and their linkages
- Evaluating all elements affected by a change, across all design and construction phases
- Automating workflow processes for change review, approval and implementation
- Coordinating changes into operational systems of different parties
- Coordinating changes into a shared project management system
- Coordinating people's activities (including notification, reminding, monitoring, etc.)
- Coordinating the distribution and management of documents and drawings in up-to-date versions
- Day-to-day process and cost recording
- Dispute resolution procedure
- Change traceability and post-change analysis

All the above objects or modules are required to have cross-reference links to each other as well as linkages with changes and regular transaction systems. In this way, the change management system will be effective in capturing, predicting, controlling, updating and coordinating - everything that is involved in the change process.

An integrated change management system requires technical support from different technologies, such as:

- Collaborative workflow
- System integration and ICT technologies
- Collaboration technologies and environments
- Concurrent engineering, i.e. early collaboration between the design team, owners, and the construction community during the design phase
- Web-based collaborative project management tools and online documentation
- Costing, estimation and optimization
- Building data interoperability model (BIM)
- Integration of managerial information with building information

We have other projects focusing on the discussion of some of these technologies in detail. Shen et al. [18] provides a good survey on system integration and collaboration technologies in the

construction sector. Hao and Shen [19] has done a comprehensive literature review of adaptive workflow and distributed workflow technologies. We strongly share the vision that the integration agent, web services, and workflow technologies provide a promising solution for effective coordination of product design, engineering and manufacturing activities across or within enterprise boundaries. Boddy et al. [20] reviewed Computer Integrated Construction (CIC) technologies and focused on some under-represented areas of semantically described and coordinated process oriented systems to better support the kind of short term virtual organisation that typifies the working environment in the construction sector. An outline architecture for the process driven integration in construction was proposed based on agents, Web services / composition, Semantic Web, and higher-level protocols in web services stack. We agree with many of the understandings and conclusions of [20] and strongly advocate the authors' strategy for discussing the categories of CIC technologies within the CIC research landscape (Figure 5).

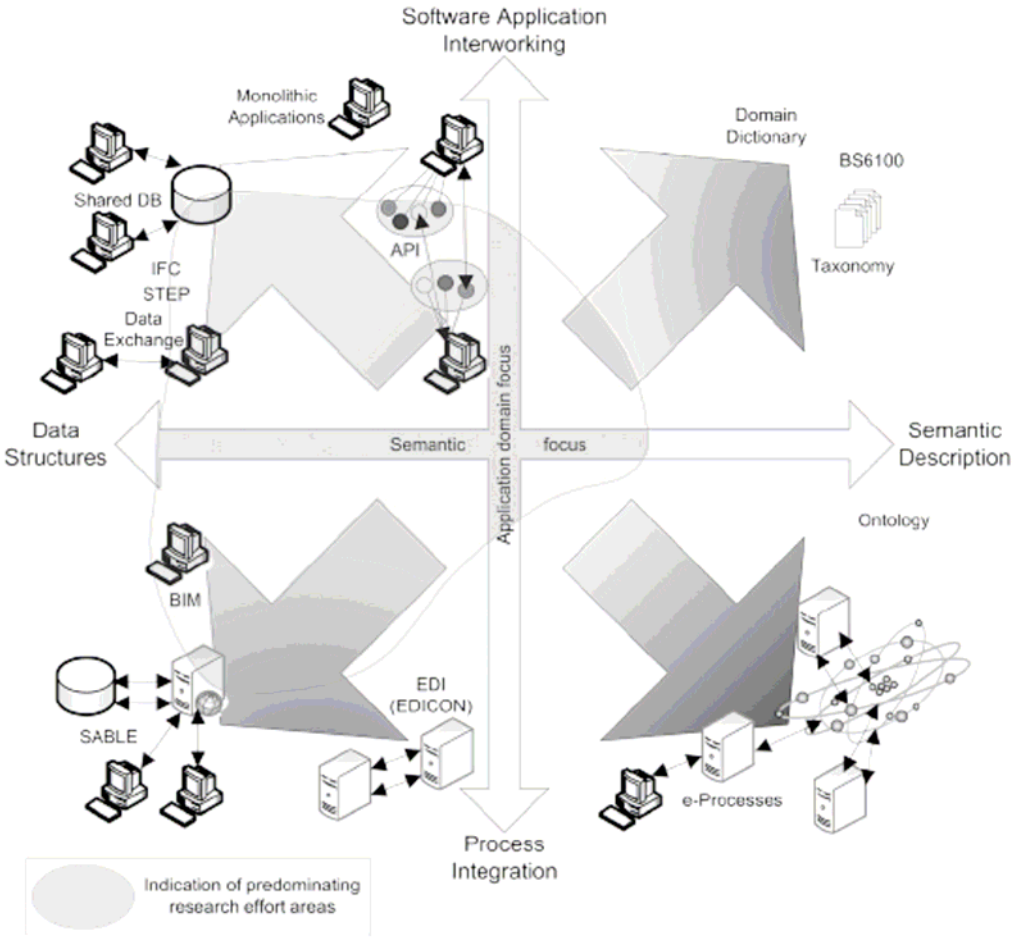

Figure 5: CIC research landscape [20]

Another report by our group [21] is focused on the need for an intelligent system in construction process automation. Based on the FIATECH's Capital Projects Technology Roadmap Vision [22], our report [21] covers related technologies such as 3D/4D modeling in automated design and engineering; intelligent material management and control for automated construction supply chains; and robotics, mobile devices and RFID, etc. for construction process automation. As a supporting system, project management and enterprise management system sits on top to facilitate the three dominant aspects of construction process automation. Change management

is a part of project management and enterprise management systems, but it can also stand alone as an independent system or as part of an integrated system with its focus on *CONSTRUCTION CHANGE* itself.

FMI and CMAA released the Eighth Annual Survey of Owners [23], which revealed that “thirty-five percent of all owners responding to the survey have used BIM processes and technology on one or more projects”; “seventy-four percent of BIM users are likely or extremely likely to recommend BIM to other owners”; and “BIM use is accelerating, and collaborative construction work processes are increasing, paving the way for construction companies to make the technological shift to BIM to better address the current needs of construction engineering programs. “ BIM is a separate topic mainly discussed in the architect, design and engineering fields. BIM is required for incorporation of design changes but it is not the core of construction change management.

9. Benefits to the industry

The construction professionals will widely agree on the benefits of having a good change management system in its construction project management portfolio.

Reduce the cycle time for construction changes
The change management system will improve the change process in many ways. The system will make sure that all relevant information is sent to each pertinent individual as soon as possible. As soon as one task is finished, the system will inform the person responsible for the next task that they can start work. If someone doesn't respond within a certain time, the system will see the backlog, remind the responsible person or pass the task to the most appropriate person. Small savings of this type will add up to significant benefits. These time savings should translate into cost reduction, faster cycle times and improved productivity.

Reduce the costs of change management
Once a change management system is up and running in a construction project, it will do many of the overhead activities associated with change management automatically, thereby reducing the number of people involved in change management and control. Also much administrative paper shuffling can be cut by employing an electronic information flow. This electronic transfer mode allows for interactive and responsive working modes between geographically distant sites. It saves time, cuts costs and provides efficient and error-free communication.

Get a coordinated information flow and document flow
A good change management system manages complex and compound documents, drawings or off-line document linkages and keeps up to date coordination of change specifications to correct document versions. This also eliminates problems that arise from people not using the latest version of information and documents. Maintaining large quantity of links between everything facilitates quick updating and propagation of change information.

Get better status on changes
It is very hard to know the up-to-date status of construction changes through the manual change management procedure in construction. It is typical that people remember a change that was approved a month ago, but don't know about anything more recent because the change is still working its way through the system. Or when downstream activities are going on, people don’t know whether these activities are done correctly because it is hard to drill through the construction activities to upper stream decisions. With a good change management system, a

user can send a simple query on-line and get the answer immediately eliminating the need to issue an RFI form and wait days to get the answer.

Improve resource utilization and co-ordination
With the process clearly defined and under control, the change system can select which people should receive tasks at a particular time. It can ensure that tasks get done in the right order by the most suitably qualified people available without continually rescheduling the entire plan. It can also ensure that those who do not need to be involved in a change can focus on their work without unnecessary disturbance, which ensures productivity enhancement and overall product development performance.

Bring engineers on different sites together to work on changes
The system will be able to work across national barriers. It will also be able to work across departmental and corporate barriers. Once the most appropriate change routing has been determined, tasks and information can be distributed anywhere on the network. Furthermore, in a collaborative change management environment, the project team will be able to coordinate their operations, tasks, and activities more conveniently than ever before.

Obtain more accurate estimates of change costs and times
A good change management should not only manage the change and the process, but also provide a good estimation on everything that might be affected by the change. One way to reach this goal is through mathematical or analytical models, and another way is to assist decision making based on the historical information of past changes, such as the resources needed, time required, cost, and the extent to which they followed the plan.

Gain traceability or an audit trail of change activities
A good change management system provides full traceability of all processes, information, documentation and relationships. The change management system controls the flow of work so it can easily provide information as to the tasks carried out on the project. This information could include, but not be limited to, the name of the person who carried out the task, when they started working on it, who they received it from, when they stopped working on it, etc. If anything goes wrong one can track back and see what has happened.

Establish better control over the “as built” to make it conform with the “as designed” or the “as changed”
Through the built-in linkages and traceability in the change management system, daily operations, tasks, activities, decisions, processes, changes, and specifications are properly intertwined. When construction is in progress, a manager will know what version of design is applied, what change order it corresponds to, what budget it is based on, and what schedule is expected. In this way, the “as built” is better controlled and is more likely to conform with the “as designed” or the “as changed”.

Assist the managers in making “smart” decisions
With a change management system, managers know dynamically what's happening with a change, and will be in control. Project risks caused by poor practice of change management are much reduced when the process is visible, traceable and controllable. Automated reporting on the progress of a change is faster, cheaper and less liable to suffer from transmission and transcription errors than manual reporting. With the right reports available, decisions could be made faster, smarter, and more accurately.

Best practices in change process are followed
Once change processes has been reviewed and analyzed, and the most appropriate layout of tasks has been identified, the organization will have the opportunity to take better control of the change process in future projects, and thereby be able to make sure that things are done properly.

10.Opportunities and solutions

One of the areas increasingly affected by technology migration into construction is project management and collaboration. According to a survey [24], sixty percent of respondents said that they relied on the construction manager or contractor to provide the software for tracking progress and creating reports. 82% said that the owner should define the procedures for formal communication between parties on the project. Since change management is a part of the construction project process, the final adaptors or drivers of change management systems will be the same stakeholder groups for project management and collaboration software -- first the owner and project manager, then the general contractor or design-build contractor. As a research facility, IRC probably should target government organizations, city municipals or professional associations as well for initiating related research activities.

Based on our investigation of the construction change management area, the poor practices and the urgent requirements in the industry versus the scarcity of literature and software tools stand for a promising opportunity for research and development in construction. While one may find a couple of project management or construction enterprise management software on the market, change management in construction is a topic that one hardly get no matter how a search is run in Google, in literature libraries, and in other sources. The existing change management module, although some software claimed to have, is mostly a feature for change information recording and document approval. Change estimation, impact analysis, post-change analysis, statistics, and more importantly, change traceability are not implemented in these solutions. Moreover, the aforementioned change management modules are developed mainly for engineering change management (ECN) for manufacturing enterprise, not tailored for the construction industry.

Change management is a pure application-oriented problem and requires engineering innovation to solve the problem. We haven’t arrived at a full solution for construction change management yet. However, a good solution must take into account the challenging situations in the construction industry and the nature of its project management practices; and requirements must be further collected from different stakeholders in order for our solution to be practical and adoptable in the long run. We need to continue researches and developments in this area in order to get insightful ideas of the problem and apply innovative technologies in the industry.

- Improve the change management model so that it contains and links different aspects in change management.
- Research the modeling and optimization of fault prediction, impact estimation, and propagation reasoning of changes.
- Propose an integrated solution for construction change management, comparing different technologies and clearly identify the distinctive features of our solution.
- Consult stakeholders; collect requirement and real-world cases.
- Design an integrated and collaborative construction change management system.
- Develop a prototype system and demonstrate to industries and consultancies.
- Develop and implement a near functional construction change management system.

11. Conclusion

Changes are inevitable in construction projects. And, during a construction project, many decisions have to be made, often based on incomplete information, assumptions and personal experience of the construction professionals. Change is a common denominator in all construction projects, although the size, scope, and complexity of projects may vary significantly from case to case. Change management is a critical problem faced with the construction industry. The effort of managing change orders has imposed a huge burden on project management. Changes are identified as the major cause of project delay, cost overruns, defects, or even project failure. More seriously, playing games on changes cause serious ethical problems and disputes in the industry.

Changes in construction projects are very common and likely to occur from different sources, by various causes, at any stage of a project, and may have considerable negative impacts. This report addresses the types the changes, as well as their stakeholders, causes, impacts and correction actions in the context of typical stages/phases in a construction project. Effectively managing change orders in construction processes is not trivial because change orders are a part of contract and they need to be strictly traced in terms of contracts, documents, approval process, payment claim, etc.

Based on a synthesis of several change process models reviewed in the literature and the characteristics of computational environments, a generic change process model is proposed which has five stages in a sequence: identify, evaluate & propose, approve, implement and review.

The industrial need of effective construction change management versus the scarce of R&D work is the fact in the construction industry. There is very limited research work addressing the change management issues specifically in the construction project management context. Building an effective construction change management system is very challenging. One can hardly find a mature software tool on the market that deals with this specific issue either. Existing change management module, that some software claimed to have, is mostly a feature for change information recording and document approval. Change estimation, impact analysis, post-change analysis, statistics, and more importantly, change traceability are lacking in these solutions.

An integrated change management system requires technical supports from different technologies, including collaborative workflow, system integration and collaboration technologies, nD modeling, web-based collaborative project management tools, and online document management tools. We haven’t arrived at a full solution for construction change management yet. More work will be done to develop innovative and practical solutions that are adoptable to industries.

12. References

1. M. Sun, M. Sexton, G. Aouad, A. Fleming, S. Senaratne, C. Anumba, P. Chung, A. El-Hamalawi, I. Motawa, M.L. Yeoh, "Managing Changes in Construction Projects," *EPSRC Industrial Report*, 2004. URL: http://www.built-environment.uwe.ac.uk/research/cprc/publications/mcd.pdf

2. FMI/CMAA Survey of Construction Industry Ethics Practices, 2004. URL: http://www.acce-hq/documents/ethics_survey.pdf

3. I.A. Motawa, C.J. Anumba, S. Lee, F. Peña-Mora, "An integrated system for change management in construction", *Automation in Construction*, 2007, 16(3), 368-377.

4. H. Lu, R.R.A. Issa, "Extended Production Integration for Construction: A Loosely Coupled Project Model for Building Construction", *Journal of Computing in Civil Engineering*, ASCE, 2005, 19(1), 58-68.

5. T. Huang, C.W. Kong, H.L. Guo, A. Baldwin, H. Li, "A virtual prototyping system for simulating construction processes", *Automation in Construction*, 2007, 16(5), 576-85.

6. Sidney M. Levy, Project Management in Construction, 5th Edition, McGraw-Hill Companies Inc., 2006.

7. Engineering Change Management Presentation, IQS, Inc, 2008. URL: www.iqs.com

8. V. Voropajev, "Change management – a key integrative function of PM in transition economies", International Journal of Project Management, 1998, 16(1), 15-19.

9. Engineering Change Management, SAP. URL: http://www50.sap.com/businessmaps/D0A45D785990457D990738D4CC4FD4C6.htm

10. M. Sun, S. Senaratne, A. Fleming, I. Motowa, M. Lin Yeoh, "A change management toolkit for construction projects", Architectural Engineering and Design Management, 2006, 2(4), 261-271.

11. O. Ipek, A. Ömer, "Tool support for computer-aided requirement traceability in architectural design: the case of DesignTrack", Automation in Construction, 2007, 16(5), 674-684.

12. S.H. Lee, F. Peña-Mora, "System dynamics approach for error and change management in concurrent design and construction," Proceedings of the 2005 Winter Simulation Conference, Orlando, FL, 2005, pp. 1508-1514.

13. R. Jongeling, T. Olofsson, "A method for planning of work-flow by combined use of location-based scheduling and 4DCAD", Automation in Construction, 2007, 16(2), 189-198.

14. Virtual Construction, Graphisoft, Inc. URL: http://www.vicosoftware.com/

15. N. Bakis, G. Aouad, M. Kagioglou, "Towards distributed product data sharing environments – Progress so far and future challenges", Automation in Construction, 2007, 16(6), 586-595.

16. C. Lottaz, D.E. Clement, B.V. Faltings, I.F.C. Smith, “Constraint-Based Support for Collaboration in Design and Construction”, Journal of Computing in Civil Engineering, 1999, 13(1), 23-35.

17. Q. Hao, W. Shen, “Collaborative Workflow Technology for Design and Manufacturing Coordination”, Proceedings of ASME MSEC 2007, MSEC2007-31179, Oct. 15-18, 2007, Atlanta, GA.

18. W. Shen, Q. Hao, H. Mak, J. Neelamkavil, H. Xie, J. Dickinson, Systems Integration and Collaboration in Construction: A Review, Proceedings of CSCWD 2008, April 16-18, 2008, Xi’an, China.

19. Q. Hao, W. Shen, A survey on advanced workflow technologies: Adaptive and distributed workflows, NRC-IMTI Technical Report, February 01, 2007.

20. Stefan Boddy, Yacine Rezgui, Grahame Cooper, Matthew Wetherill, Computer integrated construction: A review and proposals for future direction, Advances in Engineering Software 38 (2007) 677–687.

21. J. Neelamkavil, W. Shen, D. Fung, Q. Hao, H. Xie, Need for intelligent system for construction process automation, IRC Technical Report, March 2008 (in-process).

22. Capital Projects Technology Roadmap Vision, FIATECH. URL: http://www.fiatech.org/projects/roadmap/cptri.htm

23. FMI/CMAA Eighth Annual Survey of Owners, 2007. URL: http://cmaanet.org//user_images/2007_cmaa_ownersurvey.pdf

24. FMI/CMAA Sixth Annual Survey of Owners, 2005. URL: http://cmaanet.org/user_images/owners_survey_6.pdf