Construction Documents in an Information Technology Age: Exploring changes from an architectural point of view

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Abstract: This paper describes ongoing research in modeling and representing an evolving building information model from design to construction, within the context of the building life cycle. We explore changes during construction, and we revisit the role of construction documents — examining current technological developments in reality capture in enriching the building information model — with the potential to influence/improve the quality of the building. In doing so, we also describe a way of representing the multiple views of the various participants from the different domains, using an implementation of the *sorts* representational scheme.

Key Words and Phrases: Information Technology, Design Management, Construction Technology, Change of the AEC Culture

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1. INTRODUCTION

In any Architectural, Engineering, and Construction (A/E/C) project, change can be costly. Moreover, owing to the involvement of a number of participants from various domains, change may also be hard to manage. In fact, there are very few studies in the field of architecture that deal with management in practice, in particular, the management of an architectural construction project [1].

There are several issues that need to be addressed – in this paper, we consider two.

Firstly, information flow — according to the U.S. government report of July 2004, the US construction industry represents over $900 billion in expenditure in adjusted annual rates, half of which relates to commercial buildings [2]. Of this $450 billion plus, 10% is spent on estimating and plan dissemination, and another 10% is spent by manufacturers in educating architects and trade contractors regarding production selection, and in promoting sales opportunities. Sir Michael Latham, author of a report on the construction industry in the UK [3], estimates that 30% of the costs – and thus, a potential saving – lie within these information flows. He writes: "The construction industry would save up to 30% of the cost of the design-build-management cycle if it could manage information better … There is an absolute need for open exchange of information provided by true interoperability".

Secondly, technology integration — with respect to computer technology, a period of 18 months typically represents the entire economic life span of a hardware or software product. This disconnect in time scale is a key element in the constant struggle between a slow-moving A/E/C industry and a fast-paced technology, one in which the former increasingly depends on and tries to keep up with the latter. While a building can last 50 years or more, even the latest A/E/C desktop systems will be updated, at least, as many times, over the next five years, and some may even become obsolete. We believe that technology integration in the A/E/C industry should come, not from a single piece of software or company, but from an intelligent approach to "standardization".

Combining 3D visualization with a communication conduit, the Internet, for example, can considerably facilitate this process. This would allow architects and designers to develop a project on a computer and share it among all team members. There are successful examples in other industries. For instance, in the airline industry, the Boeing 777 Twinjet was virtually designed, built, and tested using this technology [4]. Their approach rendered dramatic results, including a reduction in engineering changes and subsequent costs, as well as an increase in airplane quality. This new design paradigm – namely, virtual design/build/test – offers great promise in the use of newer technology for synthesis and coordination. For instance, Ben Tucker (2001) from Beacon Skanska Construction claims that the CATIA model used in the Stata Center project can be thought of as a sophisticated 3D construction document, which serves all the different subcontractors [5]. He further mentions its importance in coordination, as the model becomes the interface between the different systems involved in the project. Another example that can be cited is the interactive linking of the CAD database to scheduling software, which clears the path for four dimensional construction models.

In this research, we examine issues relating to architecture firm/project management during the construction period, focusing on changes in the external construction document, specifically:

- How do we deal with these changes?
- How do changes affect architectural design? Also, how do these changes impinge on the architectural project?
- What are the emerging requirements for an external construction document, which includes a Building Information Model?

In a current ongoing project – involving researchers in architecture, civil engineering, and robotics – we explore deviations and changes in construction, as measured by sensors and scanners, which we incorporate into a living project model. In this project, we are developing an integrated system, which contains both as-designed data and as-built information, from construction. As a consequence, the system potentially supports interoperability. The findings from this research, which we use as supporting materials for the thesis expressed in this paper, come from four case studies of building – each from design to erection. These include: a steel structure warehouse (**A**), a pre-cast concrete factory (**B**), a cast-in-place concrete multiuse office building (**C**), and a steel and glass structural dome with cast-in-place concrete supports (**D**). Figure 1 illustrates an example of a kind of drawing set changes, taken from case study **D**.

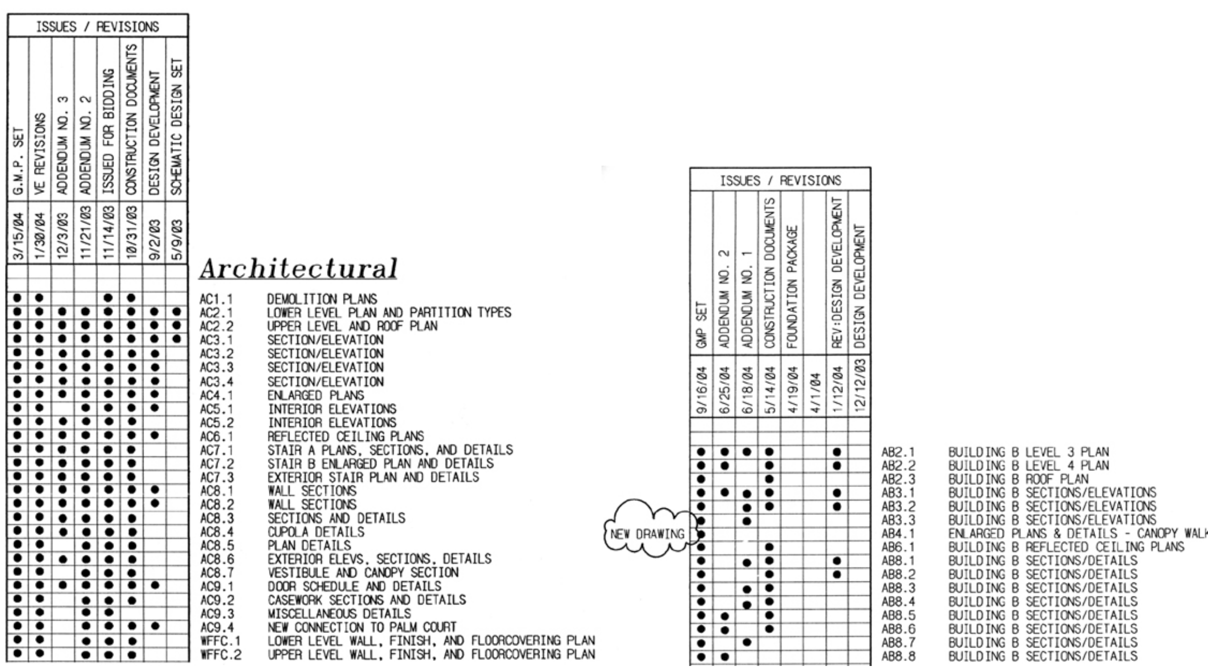

Figure 1: Examples of drawing set changes in case study **D**

2. Background Research

2.1 Documents Production in Building Design

There is more than one way of looking at the design process. For example, in a traditional studio, notions of an architectural design process are communicated in such a way as to suggest that the conclusion of the design process coincides with the design of the product. On the other hand, in actual business practices in architecture, the design process is more attuned to the firm's own type of work; these lead to office conventions that allow an architectural firm to be efficient at what it does. In this paper, we employ the architectural business practice concept of the design process. That is, architects, using professional knowledge and skills, translate abstract ideas into building forms expressed in sketches, plans, models, and specifications — together, these instruments of service provide the instructions for transforming design solutions into reality.

In the U.S., most professional bodies and large users of architectural services, for example, The American Institute of Architects (AIA), Construction Specifications Institute (CSI), US Army Corps Engineers, etc., outline seven standard stages of design, and offer a corresponding recommendation for billing of fees. The stages are: (i) pre-design, (ii) site analysis, (iii) schematic design, (iv) design development, (v) construction documents, (vi) bidding and negotiation, and (vii) construction contract administration [6]. Each stage has its own stage-specific activities and typical responsibilities, which include meetings and presentations, reviews of client information, approvals required by agencies and public bodies, and iterative building cost estimates. In architectural business practice, the "architect's basic services," as defined by the AIA consists, mainly, of tasks from five of these phases, namely, from schematic design, design development, construction documents, bidding and negotiation, and construction administration [7].

The contractual aspect of an architectural project defines the architect's services as producing submittal documents for approval by the client. It is considered as a three stage building design process. Each stage is either semi-terminal or incremental. Contracts between clients and architects identify the types of building design services (e.g., schematic design documents, design development documents, construction documents, etc.) and the tasks contained in each [8]. For example, AIA Documents B141, the most commonly used form of owner-architect agreement in the United States, establishes the scope and types of design services organized in the increments of schematic design documents, design development documents, and construction documents [9]. See Figure 1, and also Table 1, which identifies common differences between such documents.

	Schematic design documents	***Design development documents***
Contents	• General scope and conceptual design of a project. • The scale and relationships among the proposal building components.	Coordinated description of all aspects of the design, including architectural, mechanical, electrical, pluming, and fire protection system.
Primary objective	To arrive at a clearly defined, feasible concept and to present it in a form that results in client understanding and acceptance.	To archive the refinement and coordination necessary for a polished work of architecture.
Deliverables	• Conceptual site plan • Preliminary building plans with elevations and sections • Perspective sketches • Study models • Electronic visualizations • Statistical summary of the design area • Other characteristics in comparison to the program requirement	• More detailed drawings and specifications • Updated cost estimate • Preparation of estimated schedule for construction
Final step	Client approval	Client approval

Table 1: Services in Schematic design documents & Design development documents [7, 9]

The approved design development documents provide the basis for construction document increments, which are set forth in detail in the construction requirements. Depending on project delivery methods, design development increments could be significantly minimized or even skipped over.

In the conventional business model, these two increments of design, schematic design documents and design developments documents, are carelessly regarded as dispensable.

2.2 Construction Documents

In architectural practice, construction documents describe:

- What is to be built.
- How contractors are to be selected.
- How contracts for construction will be written and administered.

Typically, this constitutes a change in the status of the architect's service phase — from design to construction. The process of producing construction documents strives for efficiency, comprehensiveness, and quality. Construction documents are the written and graphical documents used to communicate the design and administer the project. Typically, it includes the following [10]:

- Bidding requirements (The invitation to bid, or advertisement; information and instructions to bidders; bid forms; and requirements for bid security)
- Contract forms (the form of agreement to be used between owner and contractor; forms for bonds and certificates)
- Contract conditions (the general conditions of the contract for construction, which outline the rights, responsibilities, and duties of owner and contractor as well as others involved in the construction process, including the architect; supplementary conditions particular to the project)
- Drawings (includes architectural, structural, mechanical, electrical, civil, landscape, interior design, and other specialty drawings)
- Specifications (outlines the levels of quality and the standards to be met in the construction of the project)
- Addenda (additions to any of these documents issued by the architect during the bidding or negotiation process)
- Contract modification (orders for minor changes in the work, construction change directives, and change orders)

Construction documents are multi-purpose:

- They communicate to an owner, in detail, what is involved in the project.
- They establish the contractual obligations between owner and contractor during the project, and also lay out the responsibilities of the architect or any other party administering or managing construction contracts for the owner.
- They communicate to the contractor the quantities, qualities, and configuration of the elements required to construct a project. The contractor, in turn, uses the documents to solicit bids or quotations from subcontractors and suppliers.
- They may be the basis for obtaining the regulatory and financial approvals needed to proceed with construction.

In order to achieve the above, construction documents include three basic types of information: legal and contractual information (generally bound into a project manual in front of the specification), procedural and administrative information (generally Division 1 of the specifications, and portions of Part 1 of each specifications section), architectural and construction information (generally found in Divisions 2 through 16 of the specifications, and in the drawings). Figure 2 illustrates CSI's format for construction documents [10]. Note that drawings constitute a part of the overall document.

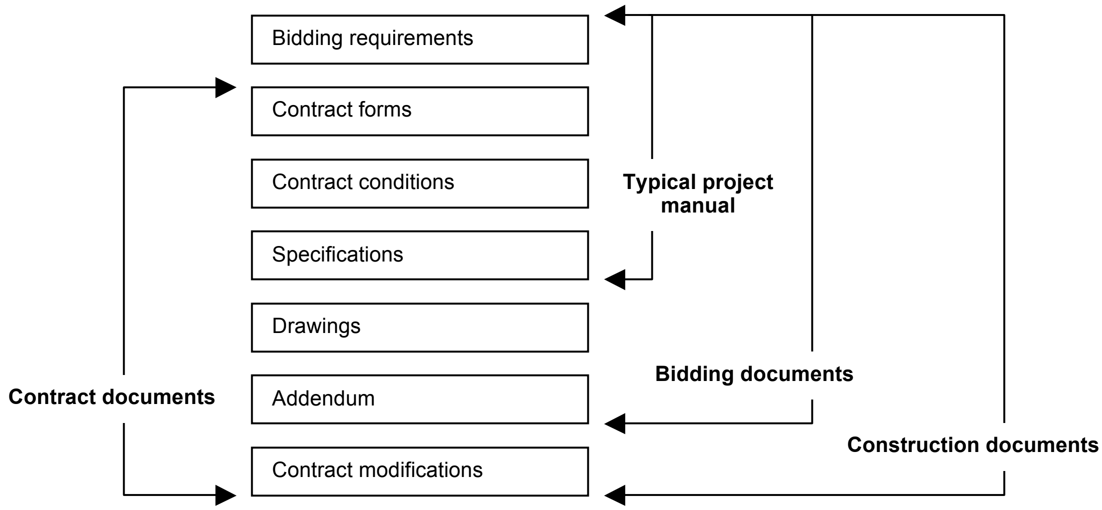

Figure 2: CSI format for Construction Documents

In its Architect's Handbook of Professional Practice [7], the American Institute of Architects specifically declare that: "*It is important that all parties understand that* ***construction documents are not intended to be a complete set of instructions on how to construct a building****. Construction means, methods, techniques, sequences, procedures, and site safety precautions are customarily assigned as responsibilities of the contractor to give the contractor full latitude in preparing bids and carrying out the construction phase. The contractor determines the assignments of work to specific trades and subcontractors. The contractor also manages logistical matters such as sequence of operations, scheduling, design of temporal supports and facilities, selection of appropriate equipment, and project safety.*"

As we all know, additionally, building projects are individually unique, and changes during any period in the building-life-cycle are inevitable and unavoidable.

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Preparing a complete specification of a building is unachievable; a physical building product has an indefinite number of potential properties, and comprises changes from diverse directions. Those parts of design that are not specified, albeit tile patterns, detailing of joints, owner decision changes, or undiscovered site conditions, are left to the contractor or building part fabricator to determine and execute.

Final design representations are currently required by law to be in the form of drawings, called contract documents, plus other written documents specifying the quality of materials and equipment specification [6]. Contract documents are widely recognized as an industry standard, and consist of forms and contracts that define relationships and terms involved in design and construction projects [11]. These documents are submitted to the regulating authority for a plan check, which is a review of the design against building code requirements. Plans are approved or returned for revision. On approval, a building permit is issued, although with the proviso that the contract documents only reflect important expected behaviors of design, to a certain degree possible, and which have been shown to satisfy specific regulations. The building permit neither specifies a terminal design, nor prohibits possible future changes.

2.3 Changes and Building Information Model (BIM)

Changes occur at various stages, and over time during design, construction, and operation. In each stage, the actors and acts are different. In the design stage, requirements such as program, budget, building codes, etc., all inform the design. The transformation of an architect's abstract ideas into a building is produced incrementally and this is reflected in the drawing sets submitted to the client. In construction, other actors come into play dealing with aspects of building such as construction project management, cost estimation, construction planning, construction safety, procurement, and so on. The role of the architect changes from designer to construction administrator. The major actors in the operation stage are the occupants and/or owners who live and use the building until the end of its life span. Occupants and/or owner may change over time; changes in usage may also occur.

In general, the flow of information changes throughout the full life cycle of the built environment. One of the movements in A/E/C industries and organizations, conducted by CSI, is entitled the "Integrated Information Initiative (III)" [12, 13]. This initiative deals with flows of information:

- Among the four teams (owners, designers, constructors, and suppliers), plus the support professionals and official bodies with which they interact;
- Across the commercial and public sectors, which will allow public works directors, university facility managers, and other community-level professionals to efficiently manage community-level resources, including public and commercial buildings, everything that connects them (roads, water mains, etc), plus the facilities and utilities that serve them (airports, sewage treatment plants, etc.);
- Throughout the full life cycle of the built environment, from initial idea through design and construction, facilities management, restoration and reuse, and finally to demolition and recycling of materials into new construction.

The CSI initiative is broad based. More narrowly, in the construction stage, current research and development in BIM [14], and web-based systems [15, 16, 17] has resulted in a new construction management paradigm that has two parts: design management and construction management (construction process through technologies). Virtual building construction, based on reality capture and intelligent recording of changes from design to erection, can predict design and construction failure before capital loss. Obviously, any intelligent record of change must be capable of generating an integrated project model that contains as-designed and as-built information. This integrated virtual building model can also be employed in the operation stage, for building performance evaluation and post-occupancy evaluation (POE). Although it is outside the scope of this paper, it is worthwhile to note that this integrated building model may be applicable in dealing with changes associated with building occupancy; see Harris' text on building pathology for aging problems associated with buildings [18].

2.4 Representational Flexibility: Employing Sorts

Design and construction activities rely on a restructuring of information that is not captured in the current information structure — that is, emergent information — as in the case of looking at a design that provides new insights leading to a new interpretation of the design elements. A conventional object-oriented approach requires a specification of design/construction elements as objects (with properties) that is maintained at all times, unless explicitly altered by the user. Then, any reinterpretation of the elements requires the specification of a (computational) change that not only fixes the source and destination object types beforehand, but also their numbers and the mapping between properties.

One of the ideas that we have been exploring with respect to the integrated projected model are computational mechanisms for representing flexibility for design and construction. One candidate is the concept of *sorts* developed by Stouffs and Krishnamurti (see, for example, [19, 20, 21]). *Sorts* presents a constructive approach to representations, based on an algebraic formalism and provides a uniform approach to handling various design data by means of a behavioral specification, based on a partial order relation. *Sorts* offers support for developing alternative design views, for data exchange between these views, and for the construction of a design query language.

Conceptually, a *sort* is a complex structure that consists of compositions of other *sorts*. At a basic level, a *sort* defines a set of similar data elements, e.g., a class of objects or the set of tuples solving a system of equations. For example, points and lines each are a *sort* and so are triangles and squares. A comparison of a *sort* with other *sorts* addresses a comparison of respective data types, their reciprocal relationship, and overall structure. The elementary data type of *sort* is defined as a *primitive sort*, and the *primitive sorts* construct a *composite sort* under compositional operation.

There are three basic predefined *compositional* operations: *attribute*, '^', which is a subordinate composition of *sorts*; *sum,* '+', specifies a disjunctive coordinate composition of *sorts*; and, *semantic identification*, ':', assigns a name to a *sort*.

Sorts can be compared and matched, for example as equivalent, similar, or convertible [22]. Table 2 specifies possible ways of comparing *sorts*.

We revisit *sorts* in section 3.5, describing our work on representing change in an integrated project model.

Comparison	***Definition***
equivalent	both are semantically derived from the same *sort*
similar	similarly constructed from the same primitive components
strongly	constructed over equivalent *sorts*
weakly	derivations from primitive *sorts*
convertible	two *sorts* are not similar, two primitive *sorts* are differ only in their arguments and constraints

Table 2: Comparing sorts

2.5 Information Envisioning in Networks

Excessive information and poor representation render complex data models difficult to understand. Building information models are good examples of vast amounts of information varying over time, and in aspect. The actors looking at specific kinds of building information also vary over time. In response, for these very reasons, the A/E/C industry has undertaken several attempts at standardizing building information models. One major ongoing development, Industry Foundation Classes (IFC), is a complex data model structure intended for use by all building industry personnel. However, from a usability consideration, IFC classes are not readily accessible to users. To visualize IFC classes, a visual dynamic graph-based interface seems a proper candidate.

Networks of classes can be rendered as interactive graphs, which lend themselves to a variety of transformations. By engaging their visual image, a user is able, visually, on screen, to navigate through large networks (just like data structures in the IFC data model), and explore different ways of arranging network components.

Visual navigation through a network is an inherently dynamic process, and steps need to be taken, especially in a large network, to prevent users from feeling disoriented and out of control [23]. Dynamic graph representation achieves this by keeping the graph looking as static as possible, and more importantly, by making sure that any dynamic change is predictable, repeatable, and reversible. See Figure 3 [24]. The associative nature of the network makes remembering its structure relatively easier while the experience of seeing a series of recurring stable visual images increases and supports persistence of user memory.

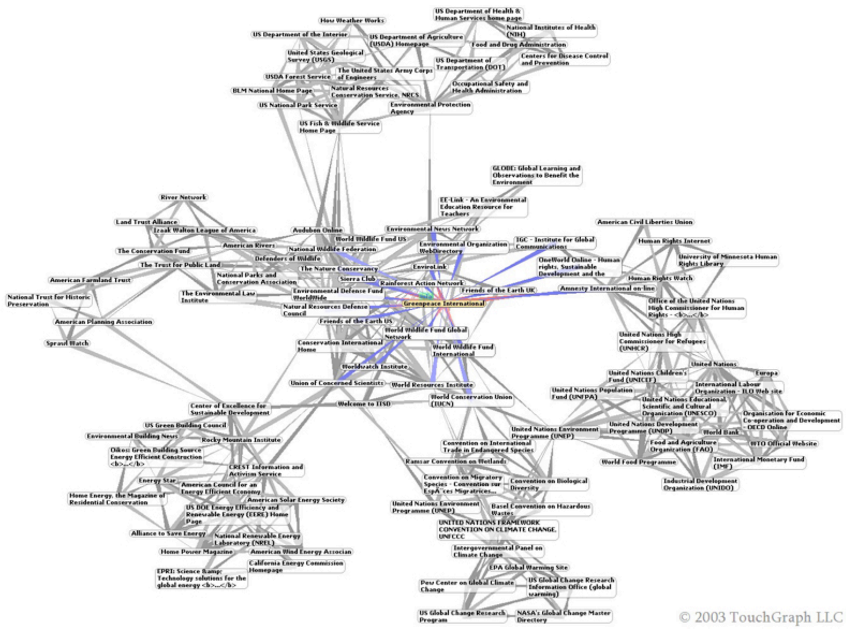

Figure 3: Example of dynamic graph-based representation of complex networks [24]

3. APPROACHES

There are certain phases in the "life cycle" of building that are common to most types of constructed entities: (i) Identity Need, (ii) Pre-Design, (iii) Design; includes Schematic Design, Design Development, and Construction Documents or Final Design, (iv) Bidding/Contract Negotiation, (v) Construction, (vi) Management, and (vii) Facility Analysis [13]. A vast amount of information is exchanged during the life cycle of a constructed entity; in most current practices, information loss occurs between and during phases. From an A/E/C perspective there is more information exchange during the design, bidding/contract, and construction phases.

In general, the construction phase includes contractor planning and scheduling activities — for example, mobilization of equipment; material purchasing; on-site and off-site construction and fabrication of components by the contractor or subcontractors; contract administration by all parties (owner, architect, engineer, and contractor) concerned with specific rights thereof; and general implementation of contract document requirements through to project closeout [25]. The contractor produces many documents such as progress schedules, shop drawings, payment applications, record documents, operation and maintenance data, and warranties. Some shop drawings, operation or maintenance data, and warranties may be prepared or submitted by manufacturers or their representatives for distribution by the contractor. These documents become part of the administrative records, and should be kept in the project file. The A/E may prepare contract modifications, such as change orders, as needed, to incorporate changes made in the project scope, time, or cost.

In the ASDMCon project (see section 3.1), our focus is on the construction phase, more specifically, on the transformation of construction documents, geared by new technology developments in reality capture, in detecting changes between a 'previous' as-designed condition to a 'current' as-built state. As part of this effort, we have so far conducted four test case studies (i) to measure the feasibility of our approach, and (ii) to discover problems. In the sequel, we discuss the overall project, work flow, integrated project model (to define and emphasize "changes" during construction), and describe the recording and representation of "changes". It is hoped that the results from this endeavor will impact on the viability of the use of BIMs in the management and facility analysis phases as well.

3.1 ASDMCon (Advanced Sensor-Based Defect Management at Construction Sites) Project

ASDMCon project is collaboration between three different disciplines: School of Architecture, the Robotics Institute, and the Department of Civil and Environmental Engineering — to investigate ways of integrating suites of emerging evaluation technologies to help find, record, manage, and limit the impact of construction defects. Recent advances in generating 3D environments using laser scanning technologies [26], and in acquiring quality information about built environments using embedded and other advanced sensors [27, 28] create an opportunity to explore the possibility of frequently gathering complete and accurate three-dimensional and quality related as-built data captured from a construction site. There are also commercially sponsored investigations in using laser scanning technology to produce 2D- and 3D-models of as-built conditions, for example, Leica Geosystems' case studies on suspension pipeline bridges using their commercial scanning package [29]. Current trends in the A/E/C industry for the use of integrated project models have shown that a semantically rich integrated project database combining multiple views of the project participants can support various project management and facility management during the construction phase [30, 31, 32, 33].

3.2 Integrated Project Model

The system for active project control and management uses a core Integrated Project Model (IPM), continuously updated and maintained, composed of a three-dimensional design model with specifications, a construction process model, and an as-built model of the condition at the construction site. The as-designed model, 3D design model with specification from construction documents, is obtained from a commercial parametric design software as an IFC file. Laser scanners provide accurate three-dimensional geometric as-built information (e.g., component identity); similarly, embedded sensors provide frequent quality related information (e.g., thermal expansion). This collection of as-built and continuously sensed information, its integration to the project model, the subsequent analysis of the project model for defects, and any consequent update of the design and schedule models enable project managers to manage defects actively. A potential benefit is the creation of an IPM history which can be advanced to the stakeholder along with the collective building information model.

Our focus is on the integration between different models: as-designed, as-built, defect, and specification models. Figure 4 shows the system integration diagram for the ADSMCon project showing the IPM at the core presenting different views and perspectives of the project, as needed, to the different participants.

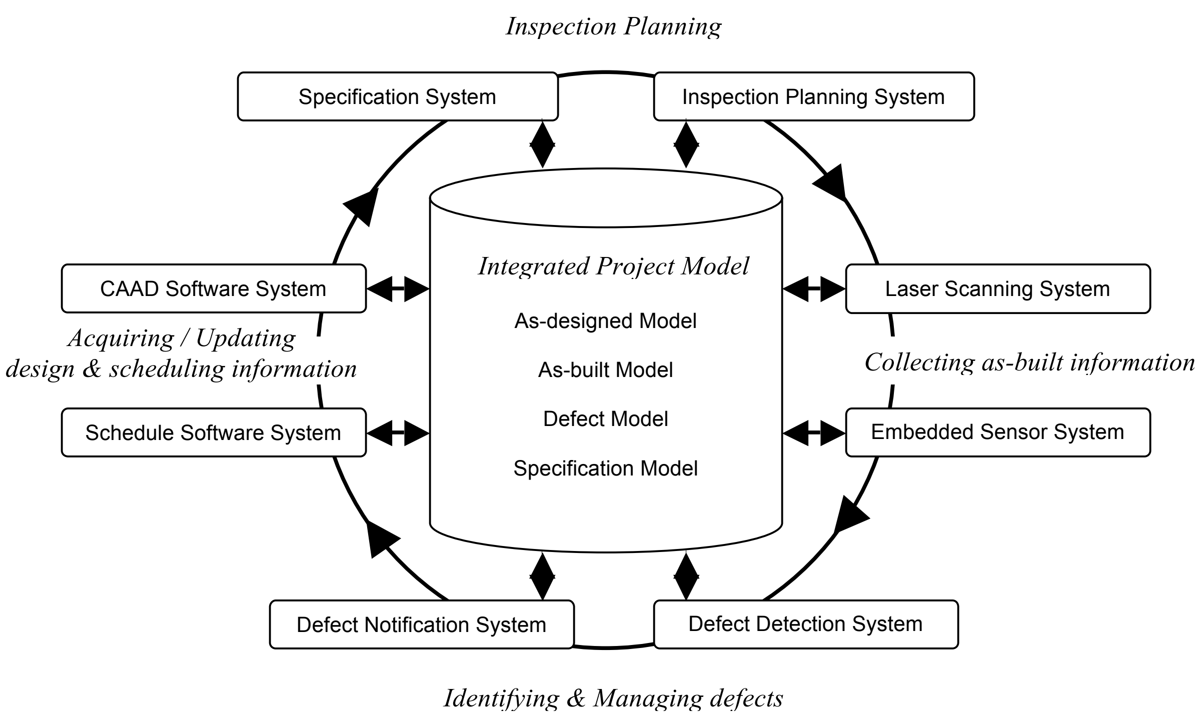

Figure 4: System integration diagram of ASDMCon project

3.3 Conceptual Project Workflow and Case Studies

Overall, the process for each case study starts with information gathering to build an IPM. The as-designed model should have a geometric level of detail that is useful for comparison, with features that are to be extracted from a current condition of construction. For non-geometric features, components must be presented with expected performance attributes that will correspond to the gathered data.

Figure 5 shows the sequence for the reality capture process, namely: (i) Initializing IPM, (ii) Developing IPM, (iii) Determining measurement goals, (iv) Planning Sensing, (v) Sensing, (vi) Analyzing, (vii) Managing. These are iterative processes each continuing until construction is completed.

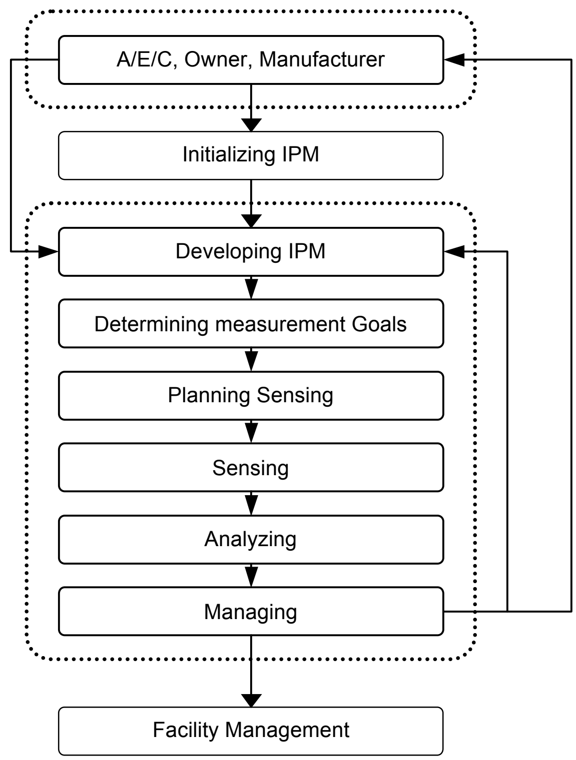

Figure 5: Conceptual project workflow

IPM initialization is based on construction documents provided by the architect. The model becomes a resource for determining measurement goals. Depending on the nature of the properties to be measured, goals fall into specific sensing methods for data collection. For example, goals with geometric information require laser scanning in order to compare specific shapes from the as-designed and as-built models. Other properties, such as temperature (inside the concrete), can be measured using embedded sensing technologies. Even when a property has no geometric relevance, distributing the sensors into a building element requires dealing with the as-designed geometry. Once measurement goals have been determined, planning for each method of data collection can proceed. For a given construction schedule, as-designed model, and measurement goals, an embedded sensing plan is made by multiple decisions of when, where, what properties, how long, and which sensors are needed. In the case of laser scanner planning, a further goal is to optimize the use of the scanner to achieve a given set of measurement goals within the construction area.

Once preparation for data gathering has been completed, actual data collection occurs at the construction site. Due to the dynamics of the site, such as the placement or erection of temporary elements (e.g., scaffolding, formwork, etc) and changes (or differences) to the construction schedule, laser scanner path planning needs to be supported by mobile computing, to update for obstacles in found at the construction site at scan time.

Laser scanning produces low data format geometry, namely, a point cloud. Although it is possible to visualize the as-built condition from this point cloud, as a representation, this low data format is computationally cumbersome for reasoning about deviations. During the analyzing stage, object recognition techniques convert the raw data into a higher-level representation, suitable for comparisons with the as-designed model. See Figure 6. Subsequently in the sequence, the as-designed and as-built models are compared, to look for discrepancies by overlaying the models within allowable tolerances described in the construction specifications. This visual inspection provides a more detailed comparison than traditional on-site inspection methods; additionally, eventually, we intend to automate this process.

Figure 6: Example of the recognition progress for a steel column from case study **B**
(Step 1: As-design model, Step 2: Range data from laser scanner, Step 3: Column recognized from Steps 1 & 2)

From our case studies we can identify changes from diverse directions — as seen from the perspective of — the architect or engineer, the construction manager, the building part fabricator, and the defect detection team. Some changes that we encountered were updates to existing building elements, and some others were, notably, new entities added to the building system, though not described in any current document. In common practice, major design changes during construction are updated in a form of Change Orders. Other changes, including the updates of building elements come from RFIs, on-site changes at owner request, etc., are not properly reflected in the building model for the next phases of the building life cycle. It seems possible, with current technology developments, to directly bring these new entities and changes into the building information model.

3.4 Modeling "Changes" in Integrated Project Model

The Integrated Project Model is a learning repository, containing traces of building evolution from design to completion of construction. It is based on the architect's design containing geometric information and some, though not complete, attribute information in a form of IFCs. As we have seen, changes are inevitable, and new entities can be triggered, by construction, into the IPM. These new entities may be used only in the construction phase, or their usage may extend into the facility management phase (for example, the uses of embedded sensors depend on their life span and/or any measurement goals set).

From the case studies, in an effort to capture the current condition on site, two new entities are added to IPM: embedded sensor data, and as-built geometric information from the laser scan. Entities are connected by way of their as-designed element identity. Embedded sensor entities have as substratum, an as-design element and a location within that element. Sensor entities contain other attributes, such as type, usage, and time-stamped values. Each as-built geometry connects to an as-designed element. Ideally, this connection is one-to-one, from one as-built surface model to one surface of the as-designed element. For the project, a new entity named "Defect" is added into the IPM. The defect entity connects to both as-designed and as-built elements through their identities. It may also include one or both sensor entity and as-built geometry.

After analysis, any newly discovered defect is submitted to a decision making process, involving stakeholders and supporting A/E/C personnel. A decision could result in: (i) a reconstruction of a part in the already built environment, (ii) a design change, or, (iii) by agreement, no further action. Furthermore, some decisions may cause other changes, such as a change in the construction schedule.

Currently, our integrated project model is designed to both capture changes in construction documents (as-designed), and changes on a given construction site (as-built). The as-designed model contains component geometry, and attribute data, such as material, install-start time, install-end time, etc. Defect and sensor data are attached to related components in the as-designed model. Change in the construction documents implies an update of the as-designed model. All attribute data and attached data are updated or copied component by component. The data of a new updated version of the as-designed model is recorded in a different subdirectory of the previous version. Consequently, our integrated project model contains all the history data (changes) in the construction documents. The as-built model records the data, which is scanned by a laser scanner periodically, and represents whatever has been built on the construction site. Each time the data is scanned, it is synthesized as a large point cloud data. It represents the latest recorded progress on the construction site, therefore records all the changes that have happened on the construction site since the last scan session. Similarly, a new scan session means an update of the as-built model, and the new scan session data is recorded in a subdirectory different from the previous scan session.

The data in the as-designed model comes from an IFC model outputted by a commercial CAD system. The Global Unique ID helps version control, but the difficulty in automatically detecting which part of the as-designed model has been changed since last version poses a potential problem.

3.5 Representing "Changes" in the Integrated Project Model

The construction phase is one of the more active periods during the building life cycle, including changes from diverse directions and of other changes (contractual, as-designed, and as-built). Over time information grows, and a building element may have multiple geometric or non-geometric representations. The participants in this phase, representationally, have their own aspect and scope. See Figure 7. It should be noted that representing this vast amount of information during construction is important for collaboration.

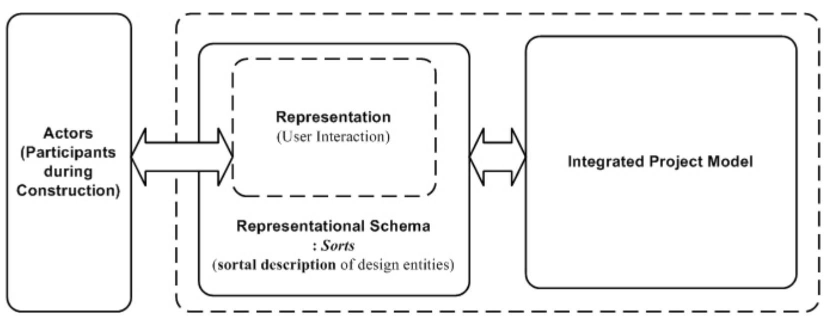

Figure 7: Representation structure diagram with *sorts* and IPM

A *general view* of the IPM is a dynamic graph representing the IPM and its component connectivity. From this general view, the *sorts* representational schema can generate a predefined *sortal description* [21, 22, 34] view of the model that is participant-specific. For increased user interaction and representational flexibility, dynamically defined views can be generated by combining components in the general view with specific functions (for example, volume calculation, face generation, etc). Figure 8 depicts the user interface architecture for the system. Figure 9(a) shows the current prototype development, and Figure 9(b) indicates the next planned interface.

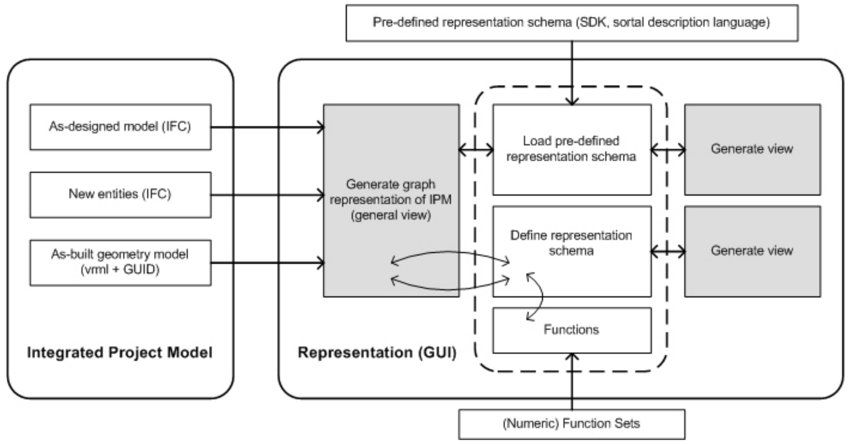

Figure 8: Current User Interface Architecture

Currently, our integrated project model successfully records changes to both construction documents and construction site. To view the changes between different versions, a timeline slider tool has been created in our system. By sliding the timeline slider, the user can view the evolution of construction documents and construction site, and compare the differences between any two stages.

4. CONCLUSTION

Construction documents specify a mid-point in the building life cycle; this is especially true in this information technology age, given the developments in building information modeling and virtual building. A building, as a building information model, grows over time; how we see this vast storehouse of information — whether at any particular point in time, or in terms of the certainty and efficiency with which we can retrieve or piece together specific information — is a major issue.

The recording and representing methods discussed in this paper provide the possibility for generating flexible views from a complex model that may have multiple descriptions of a single building element. Construction documents are specifically designed sets of information, in an ongoing evolution of a building information model.

The contribution of this research has been a revisiting of the building information model as one that evolves from design to construction, (and expectedly,) until the end of the building life cycle. The model changes over time, and includes updates, addition, and removal.

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