DIGITAL DIARY OF A BUILDING: A System for Retrieval and Update of Information Over a Building Life Cycle

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Abstract. We consider a *digital diary of a building* to be a system for flexibly retrieving and updating building information over the life cycle of the building —a system that is independent of any task-centric use. The key challenges to realizing such a system are the users and their intensions. For a practical demonstration of the notion we use IFC as the protocol for representing a building information model space and the concept of *sorts* to embrace representational flexibility. The ideas for the digital diary stem from four real construction case studies which we undertook as part of an ongoing research project.

1. Introduction

The word "building" is both a noun and a verb, an action and a result. In one sense, it is "something that is built", in another, it is "the act, process, art, or occupation of constructing" (Lexico, 2004). In this paper, we examine the notion of "building" as a whole, not only in space, but also in time. In this respect, a *digital diary of a building* is both a *document* and a *plan* — that is, the things (collectively, concepts, designs, decisions, planning, activities, uses, indeed, the whole gamut of entities associated with a building) that have happened, and likewise, the processes that need to take place.

The act of *documenting* has changed over time and will still change, by the manner in which information is captured and processed. Traditional methods include drawings and photographs, whilst current technology brings into practice novel methods of capture and measurement. Laser scanning is one such example; sensor information is another (Akinci et al., 2002). What these methods offer, both individually and collectively, is the ability to gather information about a building in a chronological fashion, and subsequently, to base design and other building decisions on a reality other than design conception. McCullough (2004) alludes to similar novel interactions and their importance in gathering information about buildings in the context of management, even though he does not specifically consider construction. Nonetheless, the reasons he supplies are just as valid for building construction.

The act of *planning* refers to the intended response to things in building related documents. Documents may and often do change. Such changes occur at different time stages in the process such as design, construction, and operation. At each stage, the actions and actors differ too. The causes of change come from many different directions. In the design stage, requirements such as program, budget, building codes, etc., inform design. At some assured point, the process moves into the construction stage. New actors deal with different aspects of building such as construction project management, cost estimation, construction planning, scheduling, quality control, and so on (Hendrickson, 2000). We then have issues of both design and construction failures. The actors in the operation stage are the occupants who live and use the building. The occupants may change over the lifetime of a building; changes in usage may follow too. Changes during operation may be diverse in nature; these, in turn, may cause other changes. In his book, *How Buildings Learn*, Stewart Brand differentiates the rates of change of its components into the "six S's": Site, Structure, Skin, Service, Space Plan, and Stuff (Brand, 1994).

Through all these—documenting, planning and change—the digital diary of a building becomes more than a repository, but a base of information gleaned from the short history of the building itself, and from others of a similar type. The central questions are: How do we *document* buildings? How do we *store* such documents? How do we *see* such documents? Not least, how do we *bring knowledge* to the planning phase?

In this paper, we propose a framework for a digital diary of a building. We focus on technologies for documentation, storage, and representation. We discuss their implications on building information modelling (BIM) efforts (Eastman, 1999). Current methods of obtaining precise information from a BIM are cumbersome. Furthermore, it is computationally expensive to produce a representation from a BIM. We discuss these issues in relationship to flexible representations that can provide different aspects and scope to different users (Stouffs and Krishnamurti, 2002, 2004).

2. Terminology and technology

2.1. DIGITAL DIARY OF A BUILDING

A *digital diary of a building* is a system for retrieving and updating building information over the life cycle of the building. It is independent of any task-centric use. By taking the normal diary—a personal journal of events over time—as a metaphor, in the context of buildings, retrieval is about seeing a view of the BIM, and update refers to the addition of new information to this BIM. These events occur periodically during the life cycle of the building.

Diaries are usually meant to be read and written by a single individual. Social interactions in cyberspace have wrought a new notion of "journal", for example, weblog, blog, blogger, etc., which are frequently written by a few individuals and shared among an undetermined number of readers. From a user standpoint, a digital diary of a building mirrors such an on-line journal; it can be seen and updated by many users. The difference is that we can assume that the users have a vested interest in the building in question.

A prevailing assumption about a BIM is that it can be developed within a single file structure that can be used throughout the lifetime of a building. We take the stance that multiple participants use a BIM according to their own interests independent of any engineering needs. For this, the digital diary of a building should be capable of being flexibly navigable over the entire building information model space.

2.2. LIFE CYCLE AND THE CONSTRUCTION PHASE

Design and construction projects proceed in phases from start to completion with variations depending on the nature of the work, the needs of the owner, and the type of contract or delivery method. The explicit start and end of a constructed entity is uncertain and depends on the point of view from which it is defined. Ideally, the concept of the *life cycle* of a constructed entity runs from the birth of an idea to the demolition of that built environment and the possible subsequent reuse of the site.

There are different ways of characterizing the building life cycle. For instance, Gielingh (1988) structures it according to its major transition phases, which he classifies as: feasibility study, design, construction planning, construction, operation, and demolition planning. Each phase involves a number of activities, each increasingly becoming reliant on computer-based operations — for example, simple drafting and scheduling tools, applications for automatic detailing and fabrication of parts and, even, automatic monitoring of building plant operations. More complex tools include material procurement and tracking for use during construction and equipment simulation for assessing equipment operation during the operation phase of a building.

At present, a serious obstacle to the use of multiple applications is the volume and nature information needed. These applications require information that defines the building over a specific context. Integration requires access, the incorporation of appropriate data, and interpretation of results with, possibly, iterative use and exchange between members of the building team. In our research, we focus on information related to construction whether it be concerned with construction management such as planning and scheduling of activities, equipment mobilization, material purchase, on- and off-site constructions, component fabrication, contract administration, or from exploring technological developments which offer new ways of capturing reality, thus providing information that might improve the quality of the constructed entity.

2.3. BUILDING INFORMATION MODEL: IFC

Constructed products tend to last long. Products may be operational for decades or longer, perhaps, outliving the project team and owner(s). Phases in the building life cycle rely on information generated in a previous phase. Standardization resolves data format incompatibility by supplying a syntactic and semantic convention, necessary for automated data exchange and data sharing. Industry Foundation Classes (IFC) is one such industry-wide standard for the digital representation of constructed entities (CSI, 1999). IFC supports information sharing within the Architectural Engineering Construction and Facility Management (AEC/FM) industry; an IFC data model facilitates the unambiguous transfer of information between computer systems. Using IFC schema definitions it should be possible to aggregate information from multiple sources for shared access and, possibly, provide a single entry-point to product information. The IFC platform specification, ISO/PAS 16739, defines data structures for representing building products and their information requirements in EXPRESS, a neutral modeling language (IAI, 2004). IFC is part of the Building Lifecycle Interoperable Software project which coordinates the implementation efforts of several vendors and more importantly, supports the idea of an IFC file as the repository medium for the building life cycle (BLIS, 2004).

On the other hand, Stouffs and Krishnamurti (2002) have argued that standardization alone is not the solution to data exchange. Any attempt to impose a common semantic model to which all adhere comes with attendant restrictions on possibly better solutions and may impede creatively new approaches to specific problems. If all adopt the same concepts, vocabulary and language, the view that data expressed within the language is accessible to each is challenged on the basis of practicality, representational flexibility and extensibility. Stouffs and Krishnamurti (2002) propose a lexical model based on syntactic similarity, with data exchange through translational mappings.

In this paper, we combine the two approaches by using an IFC data model as the BIM, and incorporating representational flexibility using *sorts* (Stouffs and Krishnamurti, 2004) in order to be able to generate user-specific views.

3. The ASDM*Con* Project

The work reported in this paper arises out of case studies from our ongoing research project, ASDM*Con* (Advanced Sensor-based Defect Management at CONstruction Sites). This collaborative project involving the School of Architecture, Robotics Institute, and Department of Civil and Environmental Engineering investigates ways of integrating suites of emerging evaluation technologies to help find, manage, and limit the impact of construction defects. Its focus is on the transformation of design documents, geared by technology developments in reality capture, in detecting changes between a ‘previous’ as-designed condition to a ‘current’ as-built state.

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

Figure 1 shows the system integration diagram for the ASDM*Con* project showing the IPM at the core presenting different views and perspectives of the project to the different participants.

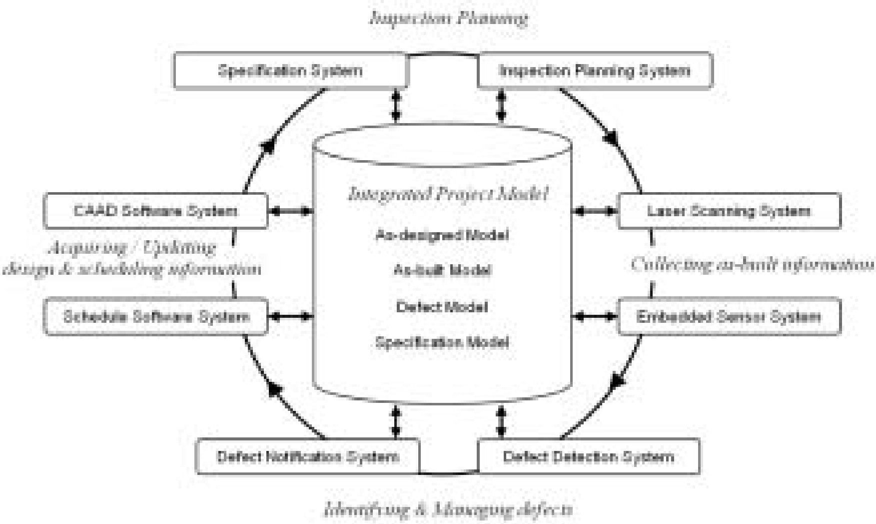

Figure 1. System integration diagram of ASDMCon project.

3.1 CASE STUDIES

We have so far undertaken four case studies from design to erection (Park and Krishnamurti, 2004). These include: (i) a steel structure warehouse; (ii) a pre-cast concrete factory; (iii) a cast-in-place concrete multiuse office building; and (*iv*) a steel and glass structured dome renovation with a cast-in-place concrete entrance hall. The first three case studies were new building constructions on an empty lot; the fourth is an addition to a historic building.

Each case study started with information gathering in order to build its IPM. The as-designed model has a level of geometric detail that is useful for comparison, with features that can be compared to some current conditions in the construction. For non-geometric features, components are presented with expected performance attributes that correspond to the gathered data.

Figure 2 shows the sequence for the reality capture process, namely: (i) IPM initialization, (ii) IPM development, (iii) Measurement goals determination, (iv) Sensing Planning (v) Sensing, (*vi*) Analysis, (vii) Management. Each is an iterative process that continues until construction is completed.

The IPM is initialized based on construction documents provided by the architect. Initially, the as-designed model is the source for determining the measurement goals. Depending on the nature of the properties to be measured, these goals fall into specific sensing methods for data collection. For example, goals with geometric information (e.g., height, width, shape, etc.,) require laser scanning in order to compare between features in the as-designed and in the as-built models. Other properties, for example, the temperature inside concrete, are

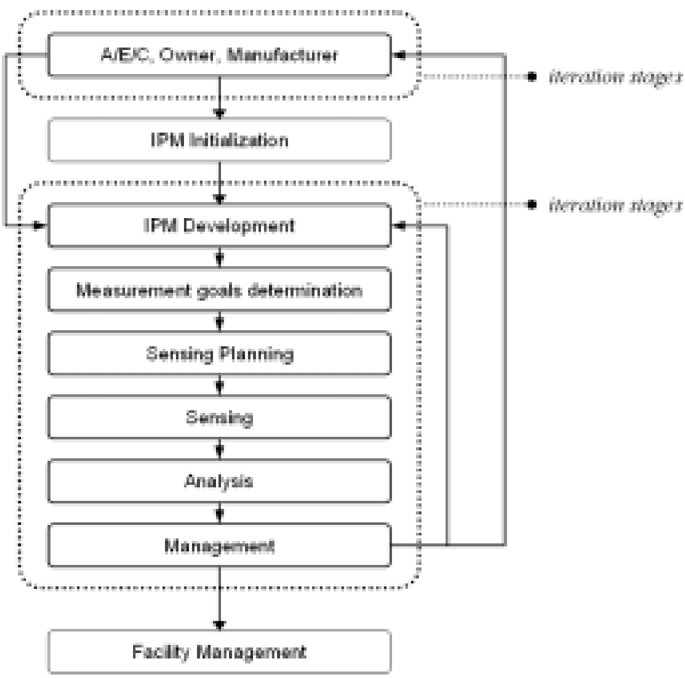

Figure 2. Conceptual project workflow in case studies.

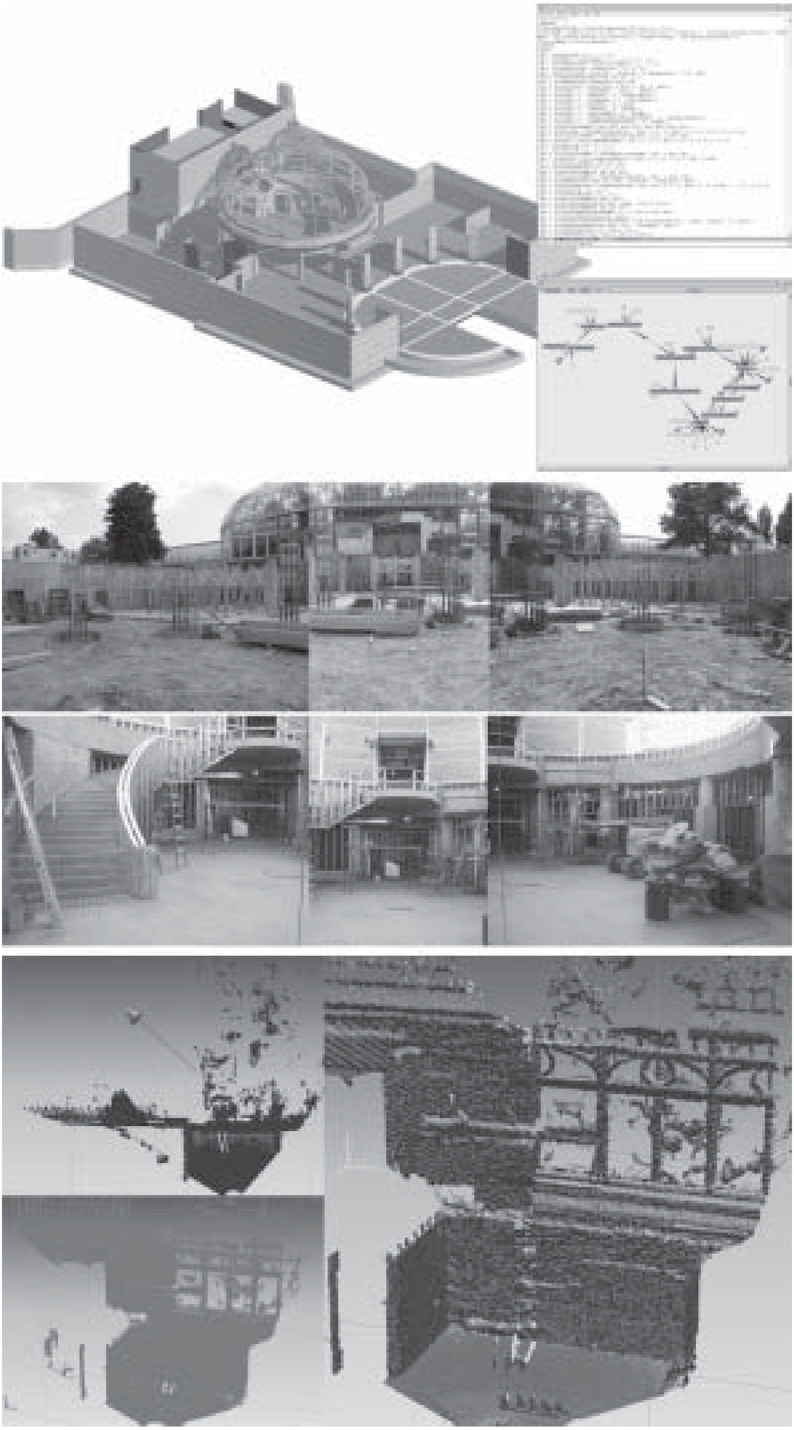

Figure 3. Case study (iv) examples; as-designed model, site condition, and as-built model.

measured using embedded sensing technology. In such situations, even when the particular property has no geometric relevance, distributing 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 proceeds. For a given construction schedule, as-designed model and set of measurement goals, an embedded sensing plan is generated based on when, where, which 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 the preparation for data gathering has been completed, actual data collection occurs at the construction site. Site dynamics such as the erection of temporary elements (e.g., scaffolding, formwork, etc.), or changes to the construction schedule require laser scanner path re-planning. This is supported by on-site mobile computing that updates the scan plan to account for obstacles found at the construction site at scan time.

Laser scanning produces low data format geometry, namely, a point cloud. It is possible to visualize the as-built condition from this point cloud. In the analysis stage, object recognition techniques convert the raw data into a higher-level representation suitable for comparison with the as-designed model. Subsequently in the sequence, the as-designed and as-built models are compared, to look for discrepancies by overlaying the models within allowable tolerances prescribed in the construction specification. This visual inspection provides a more detailed comparison than traditional on-site inspection methods; eventually, we intend to automate this process.

4. Digital diary of a building

4.1. FRAMEWORK / PROTOTYPE DEVELOPMENT

Recall that we use the notion of a digital diary of a building as a system for retrieving and updating building information in any period of time over the life cycle of a building. It is possible that any specific user is unaware of the contents of the BIM; perhaps, this user has not been previously defined. In order to deal with these issues in a retrieval process, such a system would need to provide: (i) *a general view* of the building information model, (ii) *a pre-defined view* that is generated from some pre-defined representational schema for the defined user, and (iii) *a user-defined view* for the unspecified user. Notice that (iii) subsumes (ii) and that the diary can be boot-strapped given the capabilities of (i) and (iii).

In case of updates, the system needs to be able to restructure the building information modelling space — viz., the IFC data model used in the project — and to be able to validate this protocol. Currently, the updates fall into two categories:

reflecting the data collected at the construction site, and the other, user generated, e.g., the construction inspector. There are two types of information added to the IPM from the construction site: as-built model and embedded sensor information. The information is linked to the as-designed model through component identifiers. User updates are expert "comments", which can be made at any moment in the building life cycle. These comments link to one or more components in the IPM.

The conceptual user interaction diagram between the IPM and user is shown in Figure 4. User retrievals and updates are in the representation space. This consists of the general view and the *sortal* representation of the IPM. The *sortal* representation provides flexibility to generate both pre-defined and user-defined views. (Stouffs and Krishnamurti, 2002, 2004)

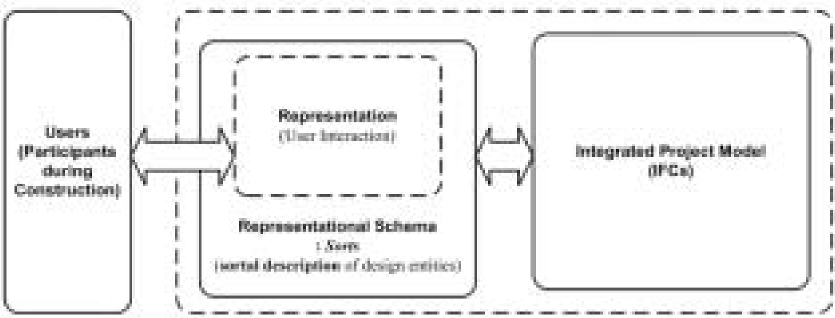

Figure 4. Conceptual user interaction diagram.

The general view of the IPM is a dynamic graph representation of the IPM and indicates the connectivity among its components. From the general view, the *sorts* representational schema generates a pre-defined *sortal description* view of the model

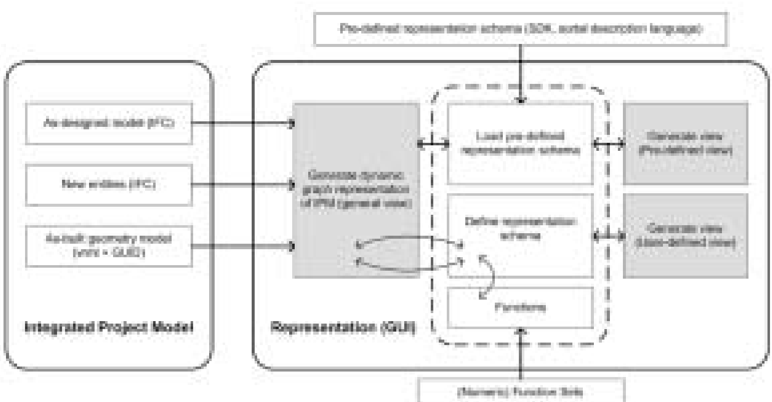

Figure 5. Current user interface architecture.

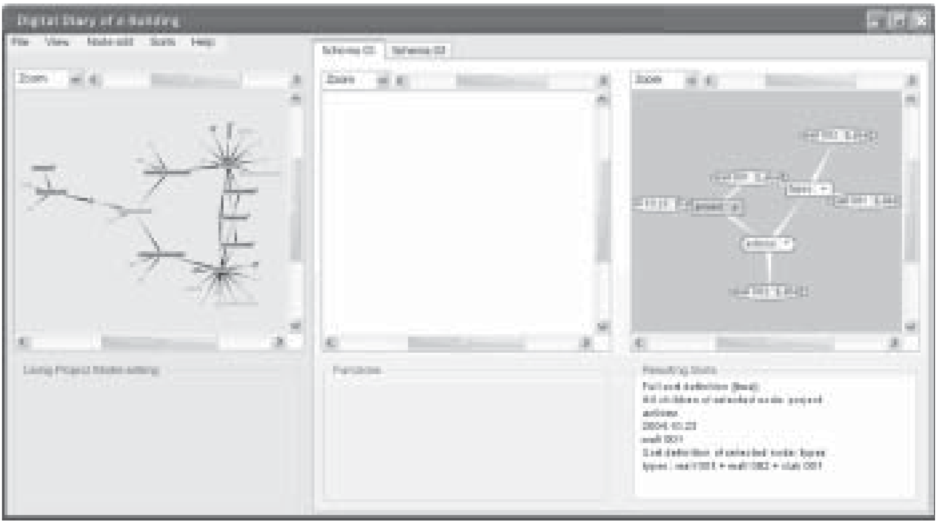

Figure 6. Current development.

that is participant-specific. We have previously given a sortal description for example construction situations (Park and Krishnamurti, 2004). User-defined views are dynamically generated by combining components in the general view with specific functions (e.g., volume calculation, face generation, etc.). Figure 5 depicts the user interface architecture for the system, and Figure 6 shows the current prototype development.

4.2. Conclusion

One of our main focuses in developing this notion of a digital diary of a building is to preserve the structure of a building information model over the evolution of the building. Any information collected be it from the use of advanced technology or from expert users is of value both for the current status of the building and for whatever consequences that this may impinge upon over the life cycle of the building. In present-day conditions, this information has to be represented digitally and any implications have also to be represented digitally. In this paper we have considered three ways of retrieval: the general view, the pre-defined view, and the user-defined view. The general view serves as a navigational tool of the entire building information model space. Users can retrieve specific information through specific representational structures either pre-defined or dynamically.

Further directions for work lie in the area of visualization, connections to external data and in dealing with the emergence of new information even from the existing building information model structure.

Acknowledgements

The project is funded by a grant from the National Science Foundation, CMS #0121549. NSF's support is gratefully acknowledged. Any opinions, findings, conclusions or recommendations presented in this paper are those of authors and do not necessarily reflect the views of the National Science Foundations.

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