

Future Directions for a Healthcare Facility Information Management System

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Quality facility management in healthcare environments is required for smooth clinical operation and to ensure patient safety. In order to provide safety and quality in an environment of care, facility information needs to be linked to the clinical information and managed properly. To achieve this, methods of capturing, storing, tracking, and retrieving adequate and accurate facility and clinical information need to be defined. An ontology had been defined within a healthcare facility information management framework to offer a more efficient method of information organization. This ontology draws connections on identified links between clinical and facility information to support facility management response to facility related events by taking in real-time and contextual information in its reasoning. The outcome of the research is a framework that offers an efficient and effective method for managing facility related healthcare information. This paper summarizes work done to develop the ontology through case study analysis methods, research outcomes, and future directions of work.

Key Words: Healthcare, Facility Management, Building Information Modeling, Information Management, Ontology

Introduction

Within the healthcare environment there are two major parties that need to work together within the same place to promote patient well-being and safety. These are clinical operations and facility managers. Traditionally, communication between the two parties is limited to when something goes wrong and facility managers get a call to fix it. Otherwise, facility management is expected to keep the systems that support clinical operations in working order without affecting clinical operations. As technology develops and the amount of information related to building systems and technologies increases, the relationship between facility managers and clinical operations has become more dependent while their information systems stay independent. The information within the facility is therefore fragmented. This disconnect of information management is in two directions. The first disconnect is throughout the facility's lifecycle between consecutive phases with disjointed information transfer. Information that is transferred through design and construction to facility management is often not in a usable form for facility managers. This disconnect also includes facility upgrades and repairs. The information related to the facility is typically found in multiple systems, binders, stacks of drawings, or more recently in digital models and is not easily sortable or navigable. The second disconnect is between concurrent activities, such as between facility managers and clinical personnel during the operation phase of the building. In order to address these disconnects a healthcare facility information management framework in the form of a Building Information Modeling (BIM) environment was proposed (Lucas et.al., 2011).

The paper presents the designed framework and future research directions. The designed framework offers facility managers a more efficient and effective method for The designed framework aims at seamless information flow by capturing the information from throughout the facility lifecycle and integrating it with relevant clinical and facility management information in the same model. Using concepts of context aware networking, where the network is able to understand the type of content that is requested based on the context of the search, the BIM framework ontology connects to other systems and real-time data to supply the facility manager with the needed information in responding to the events. The ontology allows the user of the system to efficiently query information and it will return adequate data in the correct context back to the user.

Ontology

Ontology development has been used in the information technology field for several decades as a method for researchers to define a common vocabulary to share information in a domain. Reasons for developing an ontology is to share a common understanding of the structure of information, to analyze domain knowledge, or to enable reuse of domain knowledge (Noy and McGuinness, 2001). In this research, the domain is facility management of healthcare facilities and the information is an overlap between clinical information and facility information that is used to support facility management activities. In order to develop an ontology, Noy and McGuinness (2001) define a simple knowledge engineering methodology to (1) determine the domain and scope of the ontology, (2) look for existing ontologies (or data systems) to reuse or adapt, (3) create a vocabulary of important terms to use that represent the domain knowledge, (4) define classes of information and a hierarchy based on the vocabulary, (5) define the properties of each class, (6) define the types (values) of each property, and (7) create instances of the classes to populate the ontology with information. These are the basic steps that were followed in the ontology development methodology of this research.

Applications of Ontology in Literature

Within the healthcare industry there are different systems that are in use for both clinical and facility operations. Within each side of the industry some of these systems are able to communicate information through the development of various types of ontologies (ex. Electronic Healthcare Records (EHRs)(Rector, et.al., 2009)) but there are still systems that are important to the everyday operations of a healthcare facility that duplicate information entry because of a lack of data interoperability. Within facility management, current systems have weakness for managing complex webs of information. Some of these weaknesses are that facility management systems are database driven with standard queries, and while they have decision support with adequate reasoning, they do not use information from other building lifecycle stages, they do not connect information between subsystems used for facility management, and they have limited integrated tools for monitoring and control (Dibley et.al., 2011). The incorporation of an ontology to facility management can help develop better reasoning, support improved information management, and enhance the decision support for facility managers.

Within construction and facility management ontology has been used for several years to help manage and capture information within digital models (Caldas and Soibelman, 2003; Katranuschkov et.al., 2003; Staub-French et.al., 2003). A newer trend is to use ontology to manage information over multiple information systems to support decision support. Hwang and Lie (2010) examined what parameters are needed to properly implement BIM as the central user interface for managing multiple sensor-based building control systems. Dibley et.al. (2011 and 2012) explore how to develop an ontology to help manage facilities electrical and heating use efficiency through the use of several sensor-based systems, model data, and other building information systems. In this method, the ontology supported a larger system that was aware of real-time conditions and was able to support reasoning that targeted uses of a space and allowing for more efficient lighting and heating usage based on space occupancy.

Within healthcare, ontologies are used for a range of functions in helping to classify information to enhance search performances in critical situations (Zeshan and Mohamad, 2012; Rajan and Lakshmi, 2012). Ontologies have also been used in conjunction with sensor systems and real-time conditions to help personalize medical treatment plans (Fenza et.al., 2012) and to help decide proper treatment through incorporation of clinical guides and situational context (Isern et.al., 2012; Hu et.al., 2012).

Even with these initiatives, the problem arises for facility managers in healthcare facilities that the systems on each side are not connected. There is no overlap between the clinical information systems and those used for facility management. In order to locate needed information, the user needs to look into each individual system for different types of information. In order to move the systems into a more integrated network of information, the developed ontology connects different systems that have relevant information for facility managers to complete their tasks. Much like a content aware network can take a query and supply the user with the most relevant information, the ontology would survey the different information and building automation systems for different variables and real-time data to best support the user. This can occur through the reasoning integrated into the ontology. In this sense, the ontology becomes part of a larger context aware building that is able to take real-time data from things like clinical schedules and building automation sensors, incorporate other facility and clinical data such as regulations and building component information, and support the users in their response to adverse conditions.

A Healthcare Facility Information Framework

The healthcare facility information framework targets the identified gap between clinical and facility information through the development of an ontology (Figure 1). This ontology links real-time information systems and historical information from both facility management and clinical operations. The goal of the framework and ontology is to be able to supply adequate response information based on the context of the event to facility management personnel when an event occurs by providing facility managers with a more effective and efficient method for organizing and sorting through information. Responses to events are dynamic and dependent on multiple factors. Variables that are included in the context of facility related events that influence the response are the location, symptoms of a problem (problem type), occupancy or proximity to patients, and clinical services within the affected location. Also connected to the response and following steps are the possibilities of hazards and health threats that can affect patient safety. The proper response can only be determined if the context of the situation is taken into account by connecting the variables to the proper procedures and response protocol. The only way to make this connection is for the ontology to link both facility management and clinical information and real-time data.

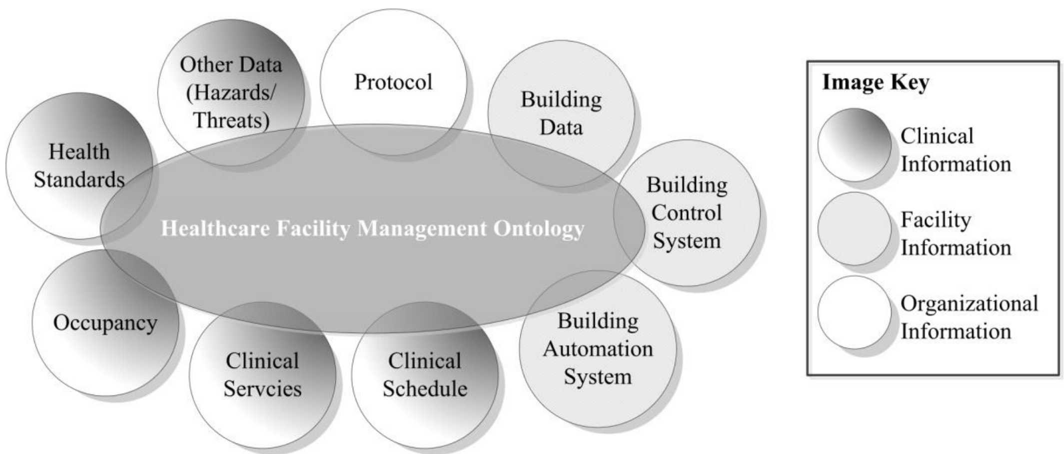

Figure 1: Systems are connected by Healthcare Facility Management Ontology.

Methodology and Ontology Development

The ontology was developed through three main steps. These included: (1) information analysis for inclusion in the ontology, (2) classification of information by types and organization of these types into a hierarchy with defined relationships, and (3) developing a user interface to allow facility managers to access the information within the ontology.

The information analysis utilized case study analysis methods as described in Lucas et.al. (2012) to identify clinical and facility management information, information systems, communications, and individuals involved in responding to real-world situations. A series of interviews with facility management and clinical personnel were held to identify possible cases for analysis. In order to limit the scope of the work, critical cases dealing with mechanical system failures that had a direct or potential impact on patient safety and care were selected for further analysis. From additional interviews about these cases, case narratives were developed that involved a step by step process of the event and ensuing response. These narratives were then documented as process models in Business Process Model Notation (BPMN). The process models allowed for documenting the involved parties and systems, the process response steps, and the decisions made along the way.

The BPMN models were then used as a basis for completing a Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) of each documented case. The FMEA and FTA analyses resulted in alternate possible failures of the involved systems and root causes for each of those possibilities, respectively. These alternate possible failures allowed for a larger understanding of possible consequences and identify a larger set of variables for the response. The FMEA and FTA analysis were reviewed by the facility management and clinical personnel for completeness and accuracy. Once these analyses were completed, Unified Modeling Language (UML) use cases were developed. The use cases allowed for documenting very detailed steps of the each activity and detail of every decision in the process. Also included were interactions between the different parties and different systems. The use cases were analyzed to develop a detailed list of needed information for each response that served as a list of vocabulary terms used in the creation of the ontology.

The second step of the research was to organize the identified information into the ontology. Similar to the process summarized above by Noy and McGuinness (2001), classes were developed from the vocabulary terms. Relationships and other properties were assigned to the classes. This was documented in the form of a product model which is a static storage of facility and clinical related information. The product model consists of both the information that is not in another system and a representation of the other systems. This representation of all involved systems within the product model helped to organize the interactions between the classes of information and in determining the needed information exchange mechanisms within the ontology. The last step of the research was to develop a system architecture that would allow the user to interact with the ontology and stored information.

System Architecture

The system architecture was designed to allow user interaction with the information within the framework and ontology. The system architecture is shown in Figure 2. The way the user interacts with the entire framework and the developed ontology is through the use of the user interface. The user interface is the median between the user and the information stored within the framework. The user is able to (A.) query the framework through the user interface. This query would be based on an event that is occurring. The interface would then (B.) send a search for the data. Based upon the context and other developed reasoning, the ontology then (C.) searches the different information types. The types of information include building related data, stored within a BIM, Clinical Information, and Facility Information within their respective systems. The results of the search is (D.) returned to the ontology, (E.) filtered based on the context of the event, and (F.) then formatted back into the user interface before being (G.) presented back to the user.

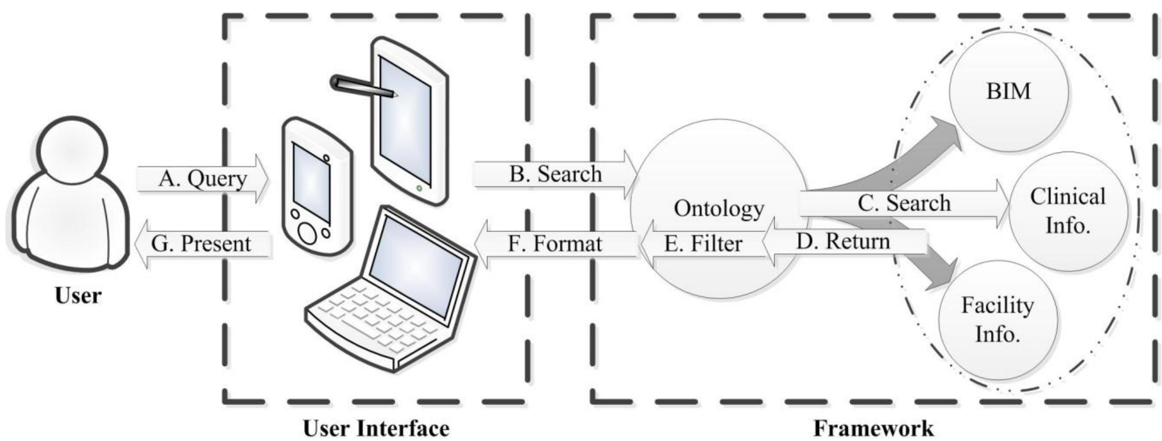

Figure 2: Framework System Architecture.

A conceptual model of a prototype was then designed to demonstrate how the user can interact with the framework. A case study was used as an example of the types of queries and responses the system can handle.

Conceptual Model of a Prototype

The purpose of the conceptual model is to demonstrate the possible use of the developed ontology and framework. It shows how the user can interact, through developed user interfaces, with the framework to retrieve information relevant to the context of the event. The conceptual model was designed by using use cases, developing Graphical User Interfaces (GUIs), and then mapping the GUIs to the developed ontology and connected information systems. The use cases allowed for determining what functions needed to be included within the system. This then allowed for efficient design of the GUIs while ensuring all needed functionality was included. In order to determine where the information was being searched and queried from, the ontology and information sources were mapped to each of the GUIs functions. This allowed for a visual mapping of how the GUIs within the user interface work to capture information from various systems and report them back to the user. The GUIs were created using Java programming language (www.oracle.com/java) within *Eclipse* (www.eclipse.org) platform. This will allow for easy implementation of the prototype for future piloting studies while allowing for the demonstration of the prototypes function within the conceptual model.

Prototype Implementation

The conceptual model of the prototype consists of different GUIs that are organized through a series of menus. Care was taken to keep the navigation of the prototype simple to allow for an easy-to-use tool for facility management personnel, especially those who are in the field. The GUIs have the menu system and allow for user inputs on the left side of the screen and allow for viewing information and interactions within the building model on the right (Figure 3).

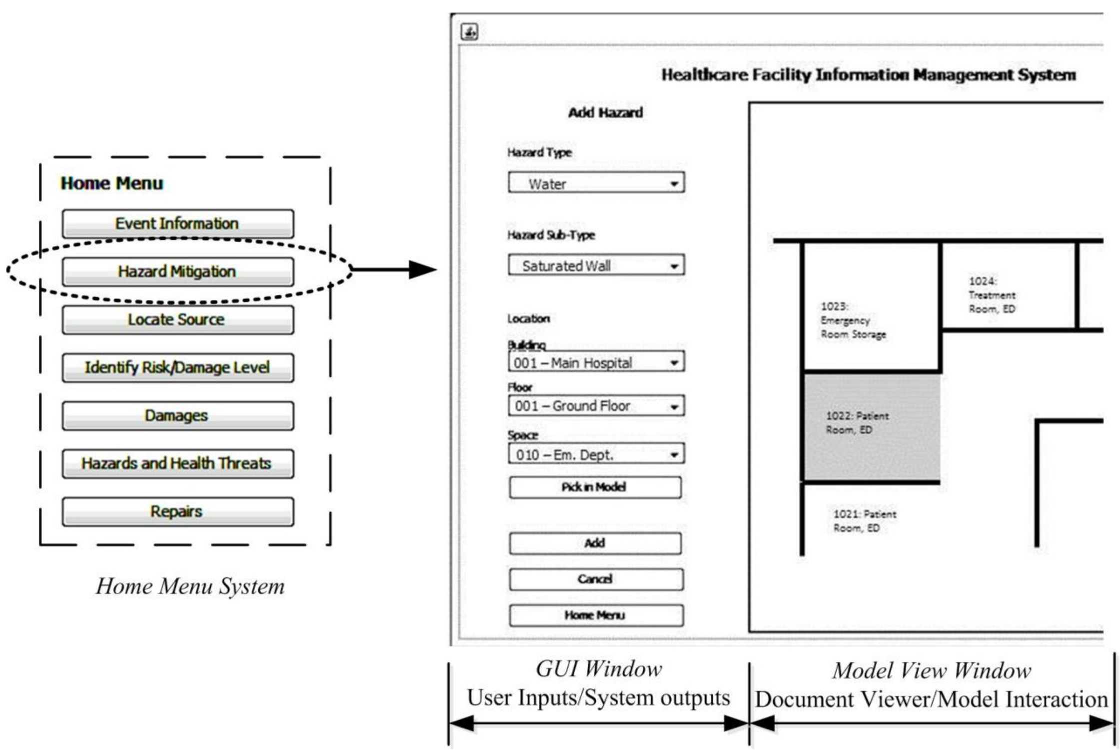

Figure 3: Prototype Interface

The interfaces within the prototype are organized sequentially to walk the user through the response of a situation. They take into account the different variables to set up the context of the event. Based on the defined variables and the event context, a proper response procedure can be followed and all relevant hazards and risks accounted for. The different functions of the interfaces are event information definition to identify the location and symptoms of the event, hazard mitigation to identify relevant hazards connected to the event and make sure they are planned for, locating the source of the problem based on the symptoms and location, identifying the relevant risks and damages, mitigating related health threats, and aiding in organizing the needed repairs to resolve the problem.

Discussion and Future Research Agenda

The completed research offers a method for a more effective and efficient management of facility related information within healthcare environments. It also directly connects relevant clinical information and systems to facility information and systems. This helps to take the context of the events into account when developing reasoning methods to help support facility managers respond to events. Several research agendas can expand from the completed research. These include furthering the development of the framework to support facility management in healthcare, applying the reasoning and ideas of organizing information for facility management to sectors of the industry that can have an applied affect, and using the methodology used to implement the framework concepts in other areas of industry.

Facility Management in Healthcare Research

One research agenda from this completed work is to expand the prototype implementation and framework. Before expanding the prototype, the developed ontology and framework with its incorporated rules will need to be evaluated against other healthcare systems. As one of the original assumptions of the research, only one healthcare system was examined and used for case study development. This was done because there are protocols and standards that are referenced by every healthcare facility. The idea was that the information types and general processes would be similar enough to adapt the system over different healthcare facilities. This assumption would have to be tested before any wide scale piloting is conducted. The framework may have to be adapted to work with other health systems. Once this is done, it can then be expanded into a larger prototype implementation with more systems beyond the original inclusion of mechanical systems.

The expanded prototype would be used for piloting and evaluating the framework. It would allow for completing usability and usefulness studies that can help gauge the function of the prototype and the users' acceptance of the developed system. As part of these studies, usability studies would be completed. These would be used to test the user interfaces that were developed. The user interface tests would examine the user's ability to efficiently retrieve the information that they are looking for and how quickly the user would be able to understand the interface. In addition to the usability study a validation study would also need to be completed. This would be done with industry professionals and make sure that the information being provided under different circumstances by the different interfaces is accurate and correct for the situation.

Another of the assumptions of this research is that the ontology would be connected to clinical and building information systems that are connected to some form of BIM containing facility system data. This is to help spatially orientate the user within the model and relate data and event information to a location. The assumption is that the BIM is available. For facilities where the model is not available, further research would need to be conducted to determine the most effective method to adopt the ontology and framework to organize the facility data.

Applied Research

Another future research agenda will be to look into areas of the healthcare and building/facility management industries to see where pieces of the framework and concepts of the ontology development can be applied. This would have a more direct and immediate impact on the industry and the ability to manage information throughout the lifecycle of a project, especially between different parties, and support owners' interests while managing the facility. This can include examining what owners of different industries need and using similar analysis methods to determine how to best incorporate the information into a usable model format. Obvious implementations would most benefit functions in healthcare, data centers, plant operations, and other facilities with complex and critical systems that need to be managed and maintained.

Use of Methodology

The last area for possible exploration is to use the methodology and larger ideas of quick information access through effective management of information for asset management. This may include campus facilities, where multiple buildings are connected to a central infrastructure. The information from the different systems and how they are connected to different assets can be managed. It may allow for more effective maintenance and operation at a macro scale and quicker response to any downtime or emergency situations.

Conclusion

The completed research discussed in this paper examines one method for improving information management for facility managers within healthcare environments through the development of an ontology. The ontology aims to provide a more effective and efficient method for organizing and sorting through information to support facility managers during facility related events in healthcare environments. As part of this research, specific links between clinical information and facility management information were identified. The ontology exploits these identified links and incorporates real-time information from both clinical and facility information systems. It takes the context of the event and helps to determine the proper response. In order to demonstrate the functionality of the ontology and developed framework, a prototype was designed to show how the user of the system, facility management personnel, would interact with the knowledge base managed by the ontology. An expanded prototype implementation is part of the future research scheme that is proposed from this research to allow for further pilot studies to test user acceptance and usability of the designed ontology.

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