A LIFECYCLE FRAMEWORK FOR USING BIM IN HEALTHCARE FACILITY MANAGEMENT

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ABSTRACT

Facility Management (FM) is important for healthcare environments to provide adequate and safe treatment to patients by maintaining the physical environment. FM activities are challenged by being disconnected from other processes within a facility's lifecycle. Within healthcare, this disconnect is compounded by insufficient communication with clinical personnel about concurrent clinical operations. Insufficient communication can lead to added risk to patient safety and additional cost to healthcare procedures. This paper describes research on identifying the information across the facility lifecycle and within the facility management and operation stage that are needed to support FM activities in healthcare environments. This information will be used to develop an ontology of integrated FM and clinical information for improving the quality of care in a healthcare setting. The ontology will be linked to a BIM. The ontology will ensure that needed information for facility operations is recorded throughout the lifecycle of the facility and allow facility managers quick access to better organized information. Focus will be on giving an overview of the methods used for determining information needs for FM activities through case study analysis. Case studies are identified through interviews with FM and clinical personnel as well as through literature review. Select cases are documented with Business Process Model Notation (BPMN) allowing for separation of steps and actors within each case. Information needs for each of the steps is determined and overlaid onto the BPMN diagrams. Lastly, the source of each information types is determined. Future work will take the information types, and their origins, determined through this analysis and apply it to an ontology. The ontology will support a BIM-based system for capturing information throughout the lifecycle of the facility in support of the operation and maintenance of the facility.

Keywords: Facility Management, Healthcare, Building Information Modeling, Ontology

1. INTRODUCTION

The maintenance and operation of the physical environment of a hospital and the use of healthcare information technologies are important for the overall quality of care and patient safety. Proper design, maintenance, and care of the physical environment have been connected to reducing patient and staff stress, improving recovery outcomes, and overall healthcare quality (Ulrich et.al., 2004). Research has also shown that Health Information Technologies (HITs) have improved quality of care and patient safety through better adherence to guidelines and protocols (Chaundry et.al, 2006), reduce medical errors, decrease health expenses (Hillestad et.al, 2005), improve physician performance, and improve patient outcome (Bates and Gawande, 2003).

Practical implementations of Building Information Modeling (BIM) within healthcare are mostly using BIM as a design and construction planning tool (Sheth, Price, and Glass, 2010; Enach-Pommer et.al., 2010). Applications of BIM for supporting operation and maintenance activities mostly consist of using laser range finding for creation of as-built models (Goedert and Meadati, 2008), creating as-built models from 2D documents for support of facility geometric information (Woo, Wilsman, and Kang, 2010), and tracking changes within models during the construction process (Akcamete, Alkinci, and Garrett, 2009).

Even with the successes of HIT implementations, there is no research effort connecting healthcare and facility management information within a HIT/BIM capacity to improve the overall operations and maintenance of the healthcare facility. This paper explores the use of BIM and ontology development to support facility information management through the lifecycle of healthcare facilities.

2. HEATHCARE FACILITY INFORMATION MANAGEMENT

Within the healthcare environment, Facility Management (FM) is in charge of operating and maintaining many complex systems that clinical staff and patients depend on in order to deliver and receive an expected quality of care. In order to maintain these systems, FM must have relevant systems information. This system information comes from various phases during the facility's lifecycle including design, construction, procurement, and delivery (Figure 1). Also during the operation and maintenance of the facility, completing work orders, renovation work, and regular maintenance that occur create more information. Facility managers need to manage all of this information properly in order to support operation and maintenance activities during the operations stage of the facility's lifecycle.

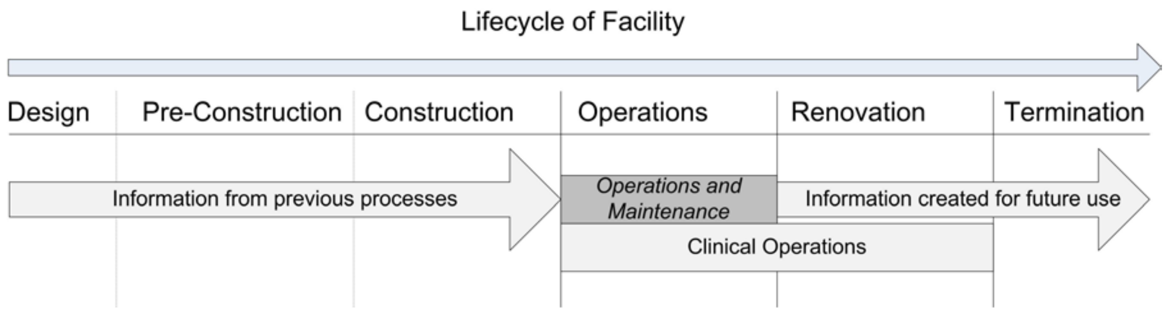

Figure 1: Information management through facility lifecycle

FM operations often need to be undertaken when clinical operations are still occurring with minimal interference to clinical activities. This requires that FM have the adequate information to do their job including air and noise quality requirements, codes and regulations, room occupancies, downtimes, and acceptable times to do work. This requires a bilateral communication and information management on behalf of facility managers. Operations and maintenance do not only rely on building systems information from throughout the facility's lifecycle within healthcare environments, they also must know relevant clinical information about processes that are happening concurrently during the operations phase (Figure 2).

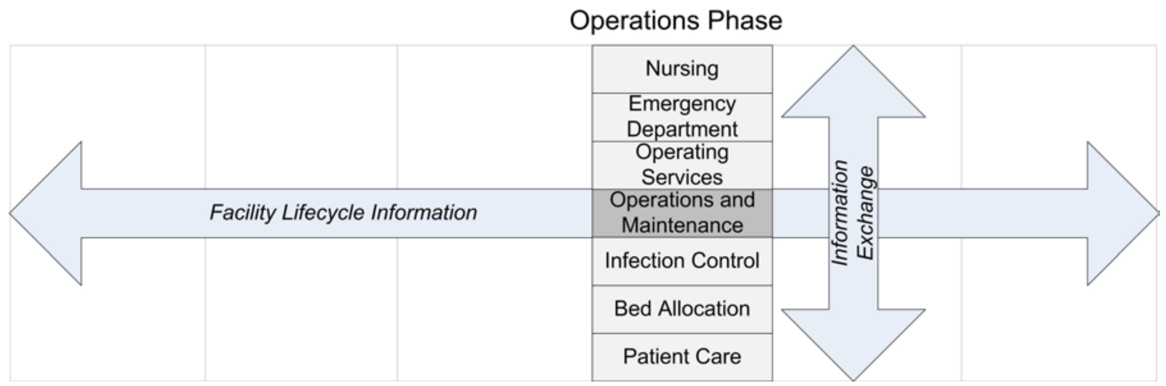

Figure 2: Information exchange within a lifecycle phase

The problem with the requirement for needing access to the vast amounts of information is that it is commonly fragmented over different information management systems and not centrally located. The information created during the building's lifecycle is often stored in different systems and created by different teams with different objectives. These different teams have poorly established lines of communication with little coherence to what information and information formats are needed by other teams completing processes later in the project lifecycle (Ospina-Alvarado and Castro-Lacouture, 2010). Information from earlier in the lifecycle is often not formatted to support operations and maintenance activities. FM as a process is often disconnected from the rest of the facility's lifecycle and the use of BIM, making it difficult to take advantage of BIM within FM activities (Goedert and Meadati, 2008). Building control systems and open contracts add to the complex nature of managing healthcare facility information. Improving communication is the key factor to the success or failure of effectively and efficiently operating, managing, and maintaining a facility with BIM (Eastman et.al., 2008; Gallaher et.al., 2010).

To complicate the situation, healthcare information is stored in completely separate systems with little to no interaction or support of FM processes. If information is not available in a timely manner it can add to the extent of damage, cause a larger down time within a healthcare service, cost the hospital in lost revenue, impact patient care by limiting services, and impact patient safety with effects on environmental quality. Downtime and taking services offline for a period of time may also be critical to the patient's care needs, it is important to have access to information and knowledge when it is needed to limit this downtime.

This research approaches the issues of mismanaged facility management within healthcare facilities by exploring the use of BIM and ontology development. The developed ontology, connected to a BIM, will allow for capturing needed information throughout the facility's lifecycle. Capturing the needed information when it is created will allow for better management of the information during the FM phase and better support FM processes. In order to ensure that the correct information is captured, case-based scenarios dealing with FM processes within healthcare environments are developed and analyzed for information needs.

3. CASE-BASED SCENARIOS

Case-based scenarios are analyzed to understand the type of events that occur and the types of information that are needed in order to properly manage those events. Topics for case-based scenarios are established through interviews with clinical and FM personnel (Table 1). The events were identified as cases were FM personnel would have an interaction with the patient, the patient's care, or a potential influence on the patient's safety. The types of information identified from the case-based scenarios will be analyzed and tracked to its origin of creation. This will help in developing the ontological framework to capture relevant information throughout the lifecycle of a facility from design through operations and maintenance. The captured information will then be stored and structured for easy retrieval during operation and maintenance events.

Table 1: Case-Based Scenario Topics

	Planned	**Unplanned**
Short Term (< 4 Hours)	o Changing Filters and Cleaning Coils	o Climate problem in room o Temperature in OR/Recovery out of range o Pressure changes in pressure environments o Leave Sink Running and Overflow
Mid-Term (4 Hours < 1 Week)	o Room Renovation o Equipment Renovation o Planned Maintenance – Limited Utilities	o Chiller/Boiler goes offline o Malfunctioning HVAC unit in OR o Pipe Burst (and remediation) o Knock off sprinkler head while cleaning (and remediation)

Long Term (>1 Week)	o Unit Renovation – containment and systems shut down o Electrical Renovation	o Mold or moisture damage previously unknown found during renovation o Chiller pipe burst/Air conditioning shut down

The topics for scenarios were separated into planned and unplanned events. Planned events are those of regular maintenance or scheduled upgrade and renovation where systems will be down or spaces will not be occupiable by clinical services. In planned situations, the typical series of events are taken into consideration and are planned for. If systems need to go down, the extent of the work is determined, prepared for, and carefully planned to the last detail. Unplanned events can be crisis situations, or when circumstances arise that are beyond the norm. These types of situations require decisions to be made quickly and information is often needed in a very short period of time. A better framework and capturing of information throughout the lifecycle of a facility would support both planned and unplanned events that involve facility management.

The scenario topics are also broken into the timeframe that they have an effect on clinical processes. Short-term scenarios are those that can be resolved in less than 4 hours, have minimal impact on normal operations and can be taken care of during the weekend or overnight. Mid-term scenarios are those that can be remedied within a week. Lastly, long-term scenarios are those that effect clinical operations for at least a week.

Once the topics for the case-based scenarios are established, selected topics related to the mechanical systems are detailed into a narrative with the processes separated into steps that were taken by various personnel when the situation occurred. Once the narrative is completed a process model is developed in Business Process Model Notation (BPMN). BPMN allows for graphically showing the steps and interactions of the process over different pools representing different parties involved in the event. BPMN also allows for including decision nodes and separation of messages and direction connections of processes (OMG 2011).

An example includes that of water incursion within the operating suite of the hospital caused by a mechanical unit malfunction. Water incursion is noted as one of the biggest threats to infection control and maintaining a healthy environment because of its relation to mold and mildew and their potential to become airborne pathogens (Sehulster and Chinn, 2003). Because of this, water incursion is taken seriously within healthcare FM. An abbreviated narrative of the case is as follows:

> A critical situation arose when the air-handler unit serving an operating room suite within the hospital malfunctioned. Water, from the chiller plant, was being pumped into the unit with a clogged pipe. Early in the morning during the weekend, the water overflowed the unit and was noticed entering the ceiling within the operating suite over a corridor and operating room. The situation required immediate mediation and determination of cause of damage before any surgery could take place within the operating suite. Care was taken by FM personnel, nursing staff, administration, and infection control to ensure that the situation was taken care of quickly and fully mitigated. Within this process, FM personnel needed to identify the source of the leak, minimize the extent of damage by taking the system offline, and then repairing the system and all damage.
>
> Since the situation occurred during the weekend and early in the morning there were no operations currently underway so no patient was put in immediate danger, however all scheduled surgeries had to be rearranged until the situation was completely resolved. Shutting down the operating suite cost the hospital a large piece of potential revenue. The cost of the physical damage to the building also added to the expenses. Lastly, directly below the leak was the storage space for surgery instruments and tools. In not knowing which tools and supplies might be contaminated from the water damage and particles that may have become airborne, they needed to be disposed of or re-sterilized. Expenses reached over $7

Million in materials and supplies with other expenses added from the operating rooms being out of service while the situation was being remedied.

The typical process for the initial response to this type of situation is shown in Figure 3. A clinical staff member reports water dripping from the ceiling to the building call center. The operator logs the call and immediately informs the on-call maintenance mechanic to go to the scene. The goal of the mechanic is to find the leak, control the situation as best possible, and then mitigate the leak or shut down the system. Not all mechanics that are on call within the building call center are knowledgeable of every system's details in the hospital. This means that when they locate the problem, they may not have the knowledge to deal with the situation. This usually requires them to call a systems mechanic who may or may not know the exact process to follow or location of a system shutoff. If the systems mechanic does not know the process or location he would need to look up the appropriate information and then go to the scene, or return the call and explain the proper processes to the maintenance mechanic. In either case, this takes more time for the situation to be mitigated and adds to the risk of the building occupants as well as to the extent of damage. Once the situation is mitigated, the on-call mechanic updates the building call center and the process to make the appropriate repairs can begin.

Water incursion within healthcare facilities can be inadvertently caused by human action, such as accidently knocking a sprinkler head off while pushing a cart of supplies and a ladder down a hallway, or by pipes breaking from age and ware. Ultimately, whatever the cause, the information needed by the mechanic to quickly remedy the situation needs to be structured, stored, and accessible in a way that would allow a more efficient and effective response process. In order to make the process more efficient the information needed to complete tasks needs to be analyzed. This is done by cognitive walkthroughs and task analysis of each task in the scenarios. The cognitive walkthroughs were conducted with healthcare FM personnel to validate the scenarios and conduct task analysis. The task analysis of each scenario helps identify the information and decisions made in both the cognitive and physical tasks completed during the scenario. The types of information are then mapped back to the facility lifecycle to locate the origin of the information. Knowing the origin of the information helps inform the ontological framework for capturing proper information throughout the facility's lifecycle.

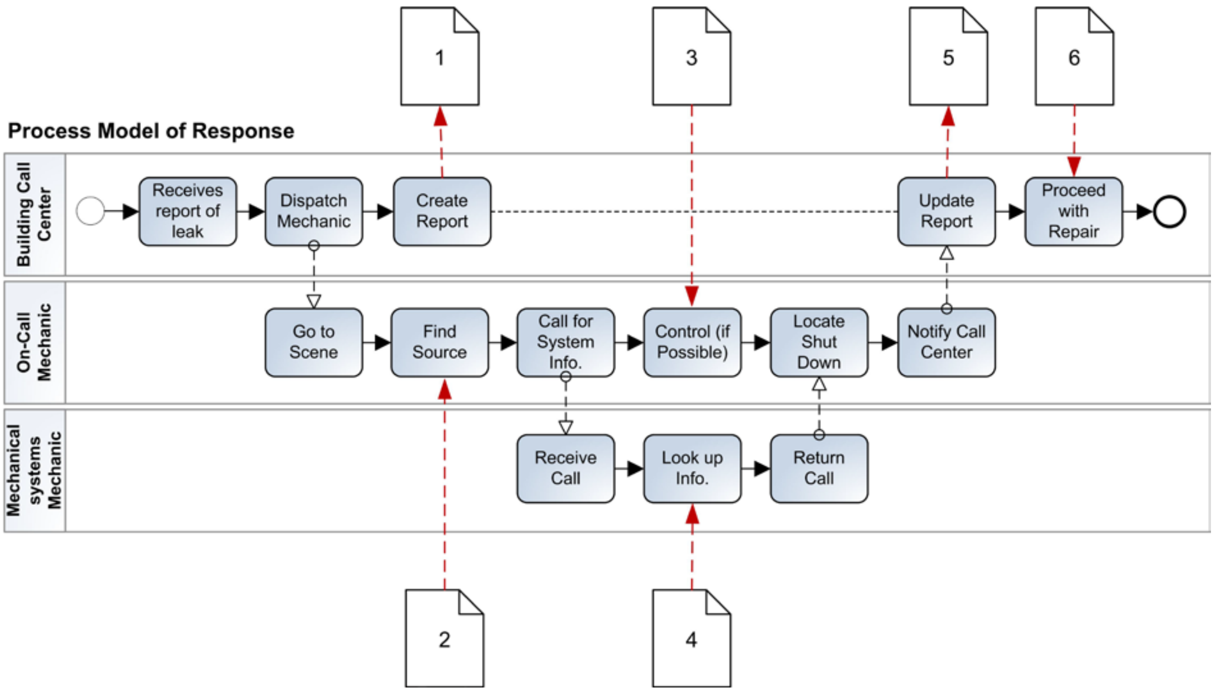

Figure 3: Process Model with Identified Information Needs

The information types needed for the scenario within Figure 3 are (1) work order information during the "create report" process, (2) systems information for the area that can cause the reported problem for “find source”, (3) available tools or methods to control the situation during “control”, (4) mechanical system plans and shut-down procedures from manufacturer specifications during “look up info.”, (5) work orders (modifying created work order in #1) during “update report”, and (6) repair procedures and protocols from the hospital’s emergency operations plan as well as systems information to “proceed with repair”. The details of each information type that is referenced during the identified process are listed in Table 2. They are also mapped to the lifecycle stage where the information originates from.

Table 2: Information details and origins

Item	Status*	Lifecycle Stages: Design	Pre-Construction	Construction	Facility Operations	Concurrent Clinical Information
		Space ID: Room/Space Occupancy				Emergency Operation Plan (EOP)
1. Work Order	C		*Filter type of systems to those that can cause problems*		Generate Work Order Work Order ID # Document Complaint Initiate Response	
2. Find Source	R	Systems in Area Mechanic Unit DWGs Plumbing Lines Sewer Lines HVAC Lines	*Determine Possible Problems*	As-built drawings	Previous Work Orders Maintenance in area Repairs on systems	
3. Control Situation	R				Emergency Tools/ Equipment and their location (ladders, water containers, etc.)	Occupancies and Threats to areas
4. System Information / Shutdown Procedures	R	*Leak location determined* Mechanical System Plans		As-built Documents Manufacturer Specs.	Previous Work Orders Maintenance in area Repairs on systems	Backup system protocol EOP Notification Procedures
5. Update Report	U				Work Order Work order update Response Cause of Problem	
6. Repair	R	*Space ID:* Mechanical System Plans Building Plans		Manufacture Info. Suppliers Contractors As-built Plans	*Conducted Repairs & Changes*	Healthcare Stnds. Moisture Testing Air Quality Testing
	U				Update As-built Plans Documented Repairs Updated Assemblies Updated Manufacturer Information, model #'s, etc.	

* C – Created U – Updated R – Referenced

Table 2 shows the type of information that responding personnel would need to reference as well as the specific details that they are looking for within each step of the response. It also links each piece of information back to a phase of the facility’s lifecycle. With knowing the specific types of information that are being looked at and where the information came from, an ontological framework can be then be created and used during the pre-construction, construction, and facility operation phase of the facility’s lifecycle to capture the needed information.

4. ONTOLOGY DEVELOPMENT

A process to develop an ontology similar to the one described by Noy and McGuiness (2001) will be used in the ontology development. The scope of the ontology will deal with information that is needed to support FM events within healthcare at the systems level. This includes the capturing of the information throughout the lifecycle of the facility at the information's origin. The ontology will be connected to a modeled environment to spatially orientate necessary information. The task analysis of the developed scenarios will be used to help compile the needed types of information. For the purpose of the research the ontology will focus on supporting events related to mechanical systems but be expandable for future inclusion of other systems.

Competency questions will be developed and used to aid in both the design and evaluation of the ontology. Competency questions are questions that the information supplied by the ontology must be able to handle (Gruniger and Fox, 1995). Some competency questions that will be used to help ensure the ontology will support the needed activities are:

> What systems in a location may cause water to be leaking?
> How do you shut down a system?
> What spaces/rooms would be affected if the system goes offline?
> What is the occupancy and use of the spaces?
> Who needs to be notified?

Capturing the needed information throughout the facility's lifecycle will help integrate the design, construction, and facility management phases and better support FM personnel in dealing with different FM events. The ontology and information included in the framework will not only help FM personnel with initial response and finding needed system information but also aid in determining extent of work to be completed, scheduling repairs, and having access to supplier and contractor information.

5. ONTOLOGICAL FRAMEWORK IN MODEL

Once the ontology is developed it will be connected to a model with specific instances of the classes being populated with information relevant to mechanical systems. This will help to test the ontology's functionality, utility, and usefulness. It will also help validate the ontology by being able to visualize its functionality with FM personnel. A Graphical User Interface (GUI) will be developed and connected to the ontological framework and model to allow accessing, querying, and editing information. Quick access to information is important so care will be taken to allow for an easy to use interface and ensuring the adequate information is returned to the user. The ontological framework will be connected to a BIM to allow for a spatial organization of the modeled information. This will help with locating information, editing existing information, and updating information (Figure 4).

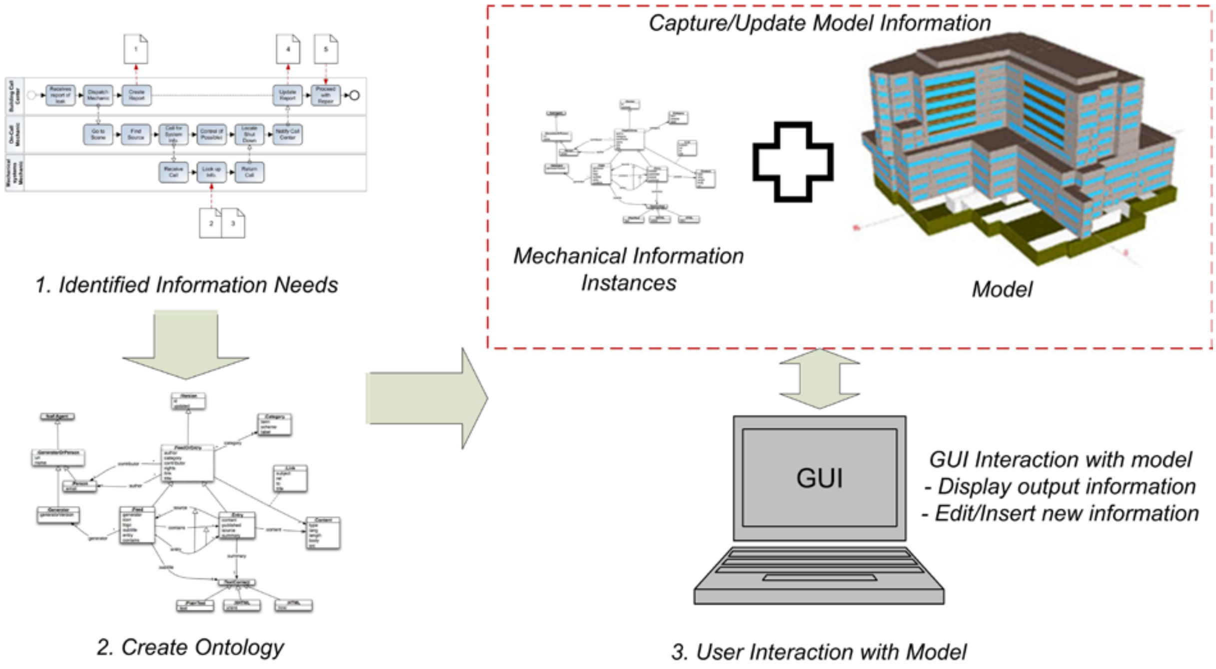

Figure 4: Process Framework

6. DISCUSSION

The goal of the research is to offer a better method of managing needed information for supporting the operation and maintenance phase of the facility by capturing and storing the needed information throughout the lifecycle of the facility. In organizing the information in a modeled environment, the hope is that it will reduce time and effort on the part of a mechanic doing the work by having all the information on hand. It can also help in modifying workflows to be more efficient and effective. The current stage of work is the case-based scenario analysis. Once this stage is completed, the ontology will be created. Instances of the classes will then populate the taxonomy created within the ontology and tied to the BIM as a prototype for accessing the information. The prototype will be used to validate the ontology as well as gauge the effectiveness, utility, and usefulness of the model-based system facility information system within the healthcare industry. The analyzed processes are specific to the healthcare facility that is being consulted during the research and some details may vary depending on the facility. The overall processes should be similar enough to support workflows in other healthcare facilities. At a minimum, the information needed to support the processes would be the same. Future research can compare other facility's processes and workflows to those used in developing the ontology to see if the system can be used and determine what modifications are needed to adapt it for wider use.

Ultimately, a full system would work on a simple tablet or hand held device to allow quick access to the knowledge at the scene of the event. The handheld system can allow for possible work flow steps and also record process steps and information about the taken actions back to the work order system. This handheld system would be tied to a central facility information management system that is controlled by office personnel who have control of editing existing model data and inputting new information (Figure 5).

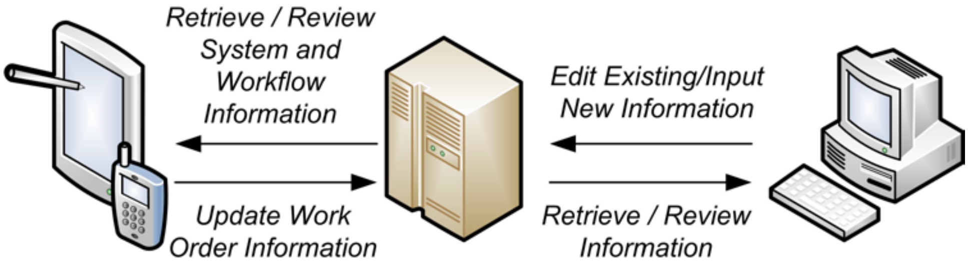

Figure 5: Future Work – Handheld Capabilities

The perceived benefits of the work include an organizational framework to allow for more effective facility information management by improving horizontal and vertical communication needs through a healthcare facility's lifecycle. In the long run, such a system can aid in reducing costs of events to healthcare systems and reduced patient safety risk. Future work may include expansion of the information tracking to help improve efficiencies within other stages of the facility lifecycle and modification of the ontology to support applications in other industries.

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