A System for Early Detection of Maintainability Issues Using BIM

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Abstract

The terms maintainability and maintenance are interrelated and often perceived to be difficult to distinguish from each other. Maintainability refers to the measures and actions taken during the design phase of a product in order to assure that the equipment and the system to which it belongs, can be easily maintained at minimum downtime and cost. On the other hand, maintenance refers to the measures and action taken during the operation phase in order to keep the components at the desired operational condition. The variance between the designers' and facility managers' priorities concerning maintainability creates a gap between the design and operation phases. Maintainability is not often considered in design nor is it a priority for designers. Designers consider maintenance access to be one of the least important factors related to maintenance. However, design-related maintainability issues such as maintenance access problems make maintenance activities impractical if not impossible in building operation, and increase the life cycle costs of facilities. These issues can be detected in the design phase if an appropriate tool is available, and can prevent maintenance-related problems in the operation phase. This research proposes a system that can be used alongside BIM and that can bridge the gap between the design and post-construction phases if deployed in the design phase.

Keywords

Maintainability • BIM • Equipment maintenance access

40.1 Introduction

Maintenance refers to measures and actions taken during the operation phase to assure that building components are at the desired operational condition. The facility manager is in charge of managing maintenance, and maintenance activities are carried out by maintenance personnel. These activities include cleaning, inspection, repair, and replacement of building components. The owner is responsible for maintenance, which is encouraged and regulated by the government, because the efficiency of maintenance affects the facility as well as the environment [1].

Maintainability is a design practice that assures maintenance activities can be performed easily, accurately, safely and at minimum cost. Building maintainability is taken into account by incorporating operations and maintenance experience and needs into the design [2]. Incorporating maintainability considerations into design requires a constant feedback from facility manager to designer, so that a common understanding between the design and post-construction phases is established [3]. However, designers and facility managers have different priorities and perspectives concerning maintainability [4–6].

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I. Mutis and T. Hartmann (eds.), *Advances in Informatics and Computing in Civil and Construction Engineering*,
https://doi.org/10.1007/978-3-030-00220-6_40

40.1.1 Research Problem

The difference between designers' and facility managers' priorities concerning maintainability creates a gap between the design and post-construction phases. This gap results in maintenance inefficiencies related to facility life cycle cost, safety of maintenance personnel, and satisfaction of facility owners and users.

40.1.2 Research Objective

This research proposes a system that can be used alongside BIM and that can bridge the gap between the design and post-construction phases if deployed in the design phase. The proposed system is applicable to all building components that can possibly be in a structure. It allows designers to check their designs from the maintainability perspective without creating extra workload.

40.2 Background

Maintainability affects the downtime of systems (i.g., MEP) and their components. Design for maintainability aims to evaluate and improve the maintainability of systems and components in case of failure or during planned maintenance. In other words, a design that considers maintainability ensures that a failed piece of equipment can be restored effectively and safely within an expected period of time and according to the prescribed operations and maintenance procedures. Considering maintainability issues in the design phase requires identification of physical design characteristics related to maintainability, reform the practices that cause fragmentation in the building design process, evaluate maintenance needs by facility type and function, understand the impact of maintainability issues on cost, and implement an automated maintainability review tool in the design phase.

40.2.1 Physical Design Characteristics Related to Maintainability

The integrity of the design in terms of maintainability requires consideration of physical design characteristics such as visual access, ergonomics, and maintenance access [7].

Visual Access. Lack of visual access to equipment significantly increases the maintenance time spent on the equipment [7]. Visual access to the display of the equipment allows maintenance personnel to perform maintenance activities safely and comfortably, because the display of the equipment often contains color codes, symbols and labels that are instructive for maintenance personnel [8]. The level of visual access is determined by whether maintenance personnel can inspect a particular piece of equipment without moving other building components [9, 10]. Especially in mechanical rooms, lack of visual access makes it almost impossible for maintenance personnel to carry out maintenance activities [11]. Lack of visual access can be considered to be a result of a design that does not consider maintainability issues properly [12].

Ergonomics. The science that aims to enhance workplace conditions and activities according to workers' physical capabilities and limitations is called ergonomics. The primary focus of ergonomics is to eliminate or minimize work-related illnesses and injuries that affect the parts of the human musculoskeletal system [13]. The minimum working space is a subject of ergonomics, and it is related to the clearance around equipment and building components. Most project specifications refer to manufacturers' manuals regarding the clearance requirements for maintenance. However, manufacturers' manuals do not provide minimum clearance requirements for all types of equipment and building components. In case the clearance requirements are not provided within the manufacturer's manual, it becomes the designer's responsibility to make a sound decision related to the maintainability of the system. Unfortunately, there is no universal clearance criterion that covers all equipment and building components. Even though a 20 to 24-in. maintenance clearance around equipment may be sufficient considering human ergonomics, applying such clearance around all equipment and building components would be inefficient from the architectural space perspective [14]. When determining the maintenance clearance around a particular piece of equipment, the type of maintenance activity must be considered, because the position that maintenance personnel must take in order to perform the maintenance activity and the size of the necessary support tools affect the minimum maintenance clearance requirement [15]. The most critical factors that cause maintenance problems in green buildings is bad human factor design [16]. According to the U.S. Department of Energy [10], in order to perform maintenance in a "green" way, equipment maintenance access must be considered in the design, from the human ergonomics perspective. Maintenance access is a universal requirement that is related to human factors and ergonomics, and it should be stated in the general conditions section in project specifications [14].

Maintenance Access. Maintenance access to building components is the most important characteristic of maintainability. Poor maintenance access affects the status of building components, jeopardizes the safety of maintenance personnel, causes rework, and requires extra work and cost. When the time spent on maintenance activities varies from the anticipated durations, it is likely that there is a maintenance problem related to maintenance access [7]. Design must consider maintainability issues in a way that equipment with low reliability are the most accessible building component that can be maintained easily, safely, and economically [8]. Maintenance access can be easily overlooked in the design phase. Checking the design from the maintenance access perspective could be the responsibility of a project member, exclusively [17].

40.2.2 Fragmented Structure of Building Design

Achieving maintainability in the design of facilities requires a common understanding established by the communication and collaboration among the various parties involved in a construction project [18]. However, these parties often have different priorities and perspectives concerning maintainability. For example, while maintenance practicality, in general, is very important to owners, it is not important to designers and contractors [4]. The key aspects of maintainability such as ease of cleaning and maintenance access are top concerns of building users while designers consider these aspects to be the least important factors related to maintenance [5]. The different priorities between the parties involved in the design and post-construction phases create a fragmented construction industry [19]. Even though the designer must receive feedback from facility managers in order to design facilities with optimal life cycle performance, this is not the case [3]. Whether maintainability is taken into consideration in the design phase depends on the designer's experience. However, it is often assumed that all designers have sufficient experience to produce a design that fully considers maintainability [20].

The current content of the programs offered at schools of architecture do not give prospective designers the opportunity to become aware of maintainability issues [21]. Facility managers have little or no involvement in the design phase. The facility manager's first involvement in the project often starts with the occupancy phase where the contribution to the design is very limited and the most influential design decisions have already been made [22]. The information related to facility management requirements, such as maintenance access, is not considered in the traditional design phase, and inappropriate space allocation occurs as a result [23]. It is suggested that early involvement of facility managers in the design phase can bridge the gap between the design and post-construction phases and can improve overall maintainability by identifying issues and avoiding potential maintenance problems [24]. When maintainability is taken into consideration in the design phase, it improves overall facility performance, enhances safety, effectiveness and efficiency of maintenance [25].

Consequences of the Gap. One of the most common problems faced by facility managers is the inability to maintain some building components in both new and remodeled buildings. Design with no maintainability consideration does not only increase the cost of maintenance activities but sometimes makes it impossible to perform maintenance [6]. Maintenance goals are not set in almost one out of every two projects, and very few of the projects meet the goals in the post construction phase [17, 24, 26–28].

The most common maintenance problems faced by facility managers due to lack of maintainability consideration in the design are as follows.

- Lack of maintenance access
- Poor space layout
- Designer's limited experience gain from the operations of existing buildings
- Lack of understanding on how system design and layout affect maintainability
- Designer's failure to communicate with facility manager.

In addition to bridging the gap, facility managers' early involvement in the design phase can improve the overall performance of construction facilities [22, 25, 26]. The expected benefits of the involvement of facility managers in the design phase are as follows.

- Ease of adoption of future changes in building systems
- Ease of maintenance, cleaning, and replacement
- Enhanced safety, security, sustainability, and functionality
- Reduced energy consumption

- Environmental friendliness
- Increased facility management efficiency
- Improved overall maintainability.

The involvement of facility managers in the design phase must be facilitated in order to solve maintainability issues. Even though facility managers can be physically involved in the design phase by employing integrated facilities design delivery methods that values the facility manager's input, it is not common. The involvement of facility managers in the design phase can be achieved more practically by using computer-based tools (e.g., BIM) that can transfer the facility management knowledge to designers [29].

40.2.3 Understanding the Cost Effect of Maintainability Issues

The impact of operations and maintenance on building life cycle cost is well understood. However, the cost effect of considering maintainability issues in the design phase has not received much emphasis. The U.S. federal government has mandated its agencies to apply energy reduction measures to all federal facilities but neglected to address the cost caused by the inefficiencies of operations and maintenance that is commonly around 50% of the overall cost [30]. Considering that the U.S. industries spend over $200 billion each year on maintenance, addressing maintainability issues in the design phase can significantly reduce the life cycle costs of facilities [31]. In other words, even though consideration of maintainability in the design phase may require some extra up-front cost associated with design services, the up-front costs would be considerably low compared to the long-term savings to be achieved during the post-construction phase [32].

The decisions made in the design phase constitute 65% of a facility's life cycle cost [33]. 20% of maintenance are caused unnecessarily by design decisions and the majority of them are related to maintenance access problems [34]. Taking into account its impact on life cycle cost, design is the most cost-effective phase to detect and resolve potential maintenance problems by considering maintainability [35, 36].

40.2.4 Implementation of Maintainability in the Design Phase

In spite of its well-known benefits, maintainability reviews have been considered to be a burden by designers [37]. Maintainability review guidelines that owners require designers to follow in the design phase can encourage designers to pay more attention to detect and resolve maintainability issues. Even though a maintainability review guideline that contains the owner's needs is a good source of information, it is difficult to design a facility according to it, because design changes often, and because reviewing each change according to a maintainability guideline creates an extra burden on the design team [11]. The traditional maintainability review is often conducted over 2D drawings, the accuracy and efficiency of which highly depends on the designers' experience [38]. Instead of a manual effort spent on designing and following a guideline, a rule set can be implemented in a 3D design tool [39]. A 3D design tool can be used to implement maintenance simulations, multi-objective optimization models, and custom maintainability checking algorithms. For example, maintenance activities can be simulated on a 3D presentation and the design can be improved accordingly [38, 39]. The statistically significant relationship between equipment layout relative to maintenance access and maintainability can be used on a multi-objective optimization aiming to achieve maintainability in the design phase [40]. Similarly, an algorithm can be used to automatically generate a 3D equipment layout that accommodates maintenance access requirements and constraints [41]. BIM is the most suitable platform for implementing an automated maintainability checking process in the design phase, because the parametric and geometric information of building components that are required for maintainability checking already exist in the BIM model [42].

40.3 Proposed System

This research proposes a system for a comprehensive maintainability checking tool that can easily be put together on a BIM platform by using an algorithm template developed in this research. The algorithm template can be customized for different building components that can possibly be in a structure. The algorithm template consists of 14 steps (see Fig. 40.1).

- Step 1. The algorithm scans all building components in the BIM model and determines whether the building component of interest exists in the model. If the building component of interest does not exist in the model, there is nothing to check.

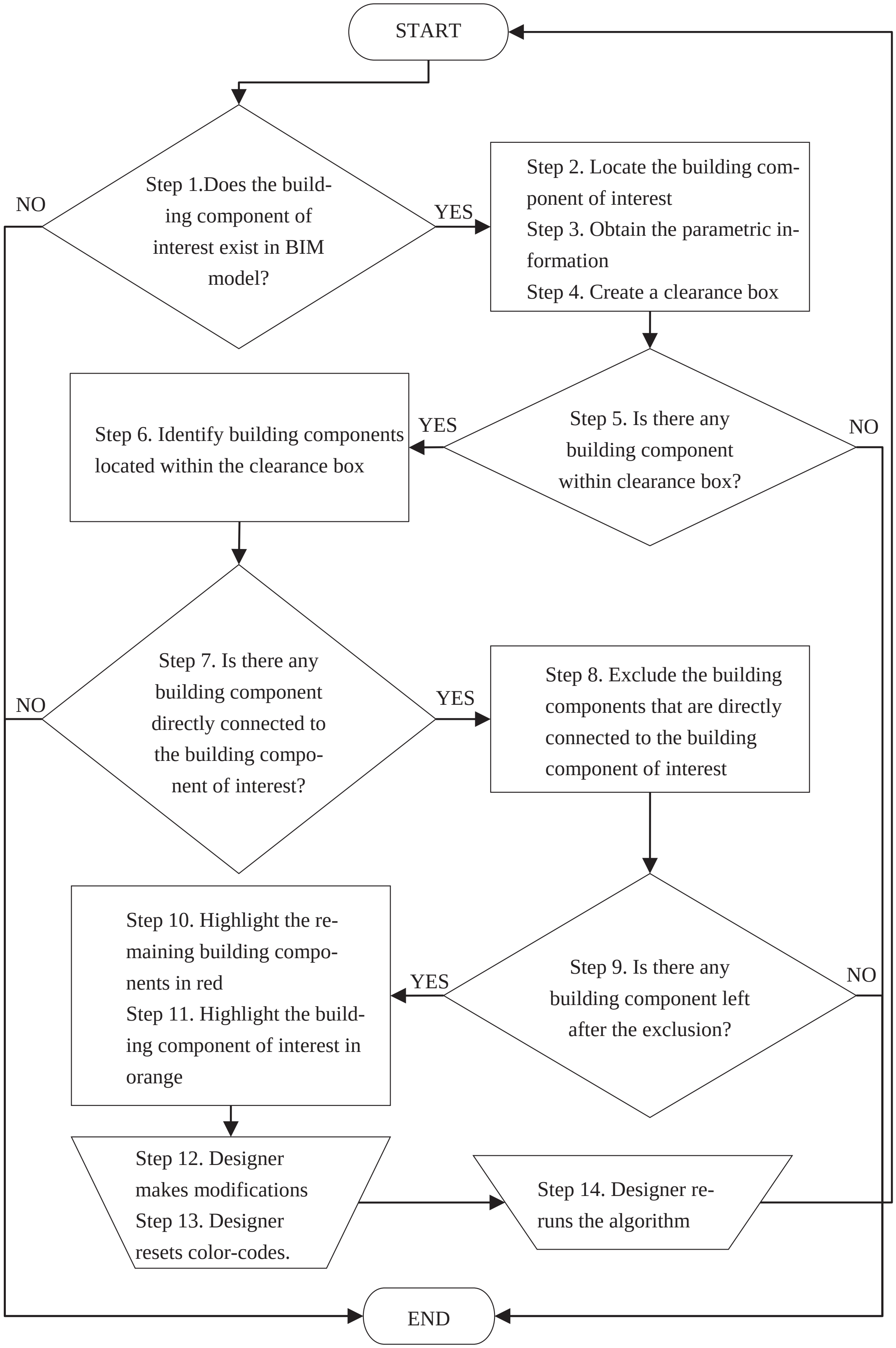

Fig. 40.1 Algorithm template

- Step 2. The location of the building component of interest is identified if it exists.
- Step 3. The parametric information of the building component of interest (e.g., local x-y-z coordinates, width, depth, and height) is obtained.
- Step 4. A clearance box around the building component of interest is created using the parametric information and the predetermined maintenance access criteria.
- Step 5. The algorithm determines whether any building component is partially or fully located within the clearance box around the building component of interest. No maintainability issue is found if there is no building component located within the clearance box.
- Step 6. The building components located within the clearance box are listed.
- Step 7. The algorithm checks whether any of the listed building components are directly connected to the building component of interest.
- Step 8. The building components that are directly connected to the building component of interest are removed from the list that is created in Step 6.
- Step 9. The building components that are located within the clearance box but not directly connected to the building component of interest are identified.
- Step 10. The building components identified in Step 9 are highlighted in red for the attention of the designer. The building components highlighted in red cause maintainability issues for the building component of interest.
- Step 11. The building component of interest is highlighted in orange in case there is (are) building component(s) causing maintainability issues. The color codes applied in Steps 10 and 11 remain until the maintainability issues are resolved by the designer.
- Step 12. The designer makes modifications on the BIM model in order to solve the maintainability issues detected by the algorithm.
- Step 13. The color-coded building components are reverted back to their default colors after the designer makes the necessary modifications.
- Step 14. The designer re-runs the algorithm to make sure the design complies with the maintainability requirements of the building component of interest.

40.4 Conclusion

Designers and facility mangers have different priorities concerning maintainability. This creates a gap between the design and the post-construction phase where maintenance-related problems occur. Some designs make maintenance activities impractical if not impossible in facility operation, and increase the life cycle costs of facilities. Potential maintenance problems can be detected and resolved in the design phase if maintainability considerations are incorporated into the design phase by an appropriate tool.

In this research, a maintainability checking system algorithm was proposed. The algorithm can be customized for all building components that can possibly be in a structure, and it can be implemented alongside a BIM tool such as Autodesk's Revit. BIM can bridge the gap between the design and post-construction phases without increasing the workload of designers, by allowing designers to produce a design that improves maintenance access and workplace safety, facilitates the cleaning and repair of building components, reduces the number of reworks, improves the efficiency of the commissioning process, and reduces the time spent on maintenance activities.

An automated maintainability checking process should be considered to be an essential part of the design process. The construction industry should create and adopt design for maintainability standards for every building component that can possibly be in a structure, and comply with them using BIM tools.

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