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Automation in Museum Construction and Operation

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Abstract. The conventional method in construction has many limitations and therefore needs modification. Not only is this method inefficient, but it is also harmful to the environment due to its high energy consumption. Therefore, there is a rising need for automation in construction. This need is accentuated in specific structures, such as museums, that are more creatively designed and have more specific maintenance and operation requirements. The purpose of this paper is to create a tool kit for automating the design, construction, and operation of museums while considering sustainability measures. The main methodology is research on the application of Building Information Modeling (BIM), robotics, and 3D printing during the design and construction stages, and examination of the integration of the Internet of Things (IOT) and indoor air quality management into the operation stage. The results are workable guidelines for the automated museum. The tool kit is beneficial as it will save time and cost and increase the efficiency of operation. It will also increase awareness of the necessity of new job opportunities for labor within the technology sector.

Keywords: Automation, Sustainable Construction, Museum Construction, 3D Printing, Robotics, Internet of Things, Indoor Air Quality.

1 Introduction

The construction sector accounts for approximately half of the total investment of a nation [1]. The prosperity of a nation's economy is therefore directly linked to the prosperity of its construction sector. However, studies indicate that the productivity of the construction industry has recently declined [1]. Hence, in an effort to increase productivity and efficiency, boost sustainability, improve working conditions, and support architectural creativity, automation in construction has become a primary focus of innovators in the industry.

Museums are highly particular institutions and hence, normally, have unique designs, structurally and architecturally. Some of the world's most respected constructed facilities are museums. Such examples include the Phaeno Science Center in Germany, New Museum in New York, and the Literature Museum in Marbach. Like any unique construction endevour, museums require intensive planning. Accordingly, the designers must look at these projects holistically. Cost, environmental impact, time, and indoor air quality are examples of the aspects that require special consideration [2]. It follows that the rising need for faster, more efficient, and sustainable construction triggers the interest in automated techniques in the construction of buildings in general, and museums in particular.

1.1 Background

Museums are highly specific structures in terms of the design requirements for their internal environment. This is due to the structures' dual functionality as centers for the preservation of historic artifacts and as educational facilities with a varying influx of visitors. To maintain the function of preservation, internal environmental factors such as humidity, temperature, and pollution must be continuously monitored and controlled [3]. A failure to do so could result in material expansion or shrinkage, mechanical failure, or texture damage in the artifacts [3]. The control of these factors can be achieved efficiently by the use of automation systems such as Building Information Modeling (BIM) during the construction of the structure and the integration of automated heating, ventilation, and air conditioning (HVAC) elements while the structure is in use. Furthermore, museums must ensure the comfort and safety of their visitors. This is easily attainable through the application of process models to control the indoor air quality and through the utilization of BIM in risk management. The requirement for an efficient risk-management system is further accentuated by the historical value of the artifacts. As illustrated in [4], BIM can be used to detect, control, and manage disaster risks by transmitting real-time information on the status of the building and predicting the optimal rescue and control route [4].

1.2 Literature Review

1.2.1 The need for automation in construction

Makarand Hastak, compares the conventional construction method with the new automated one in his paper: *Advanced automation or conventional construction process?* He evaluates whether automation in construction is feasible or not based on five main criteria. These criteria include the following: need-based criteria, technological criteria, economic criteria, project-specific criteria, and safety/risk criteria. Each of these criteria branch into sub-criteria that are also taken into consideration when evaluating the automated model [5].

1.2.2 Feasibility

Turek, et al discuss the interaction between robots and humans. The authors mention the intelligent building (IB) concept, which utilizes mobile robots while also reducing the amount of energy needed in construction. Furthermore, they propose having a bridge between the human-centric view of a building and the robot-centric one. In order to achieve this, three main goals are presented: Mapping, Localization, and Path Planning. This model uses humans' knowledge, along with existing data to recognize the different elements of a building. This is very important when communicating with robots [6]. Further studies discuss the major shift that needs to occur in the construction industry if it were to accommodate automation [7]. They provide points on the incentives for the construction industry to embrace automation and the barriers restricting the entry of robotics to many construction markets.

1.2.3 3D printing

Hager, et al. evaluate the effectiveness and future of 3D building technology. The paper describes the different methods of 3D printing such as stereo-lithography, selective laser sintering (SLS), and Fused Deposition Modeling (FM). The main advantages of 3D printing in construction are the reduction of manpower, expenses, construction time, and construction waste and the increase of customization and design flexibility. The main disadvantages are the high cost of the printing materials and the required software packages for the printers, the fact that 3-D printing is an indirect process of construction, the brittleness of a range of the materials and the yet unclear life-cycle performance of the buildings [8]. However, there have been several break-through advances in the field of 3-D printing in construction over the past few years, including the integration of BIM in the process (Wu, Wang, and Wang, 2016).

1.2.4 Building Information Models (BIMs)

Pătrăucean, et al. discuss the as-built building information models or (IB BIMs), As-built BIMs differ than the regular BIMs in the sense that they reflect the actual condition of the building or the project. Moreover, they are essencial for when the actual conditions of the building differ from the designed conditions or the as-designed Building Information Models (AD BIM) [10].

1.2.5 Process Models and Robotics

Kasperzyk, et al. present a study of the integration of re-fabrication into a Robotic Prefabrication System (RPS). The authors first explain the benefits of prefabrication in the construction industry, which include cost and time reduction, as well as increased assembly efficiency. However, the use of prefabrication is limited due to the process's inflexibility to design change. Hence, the study presents the concept of "re-fabrication" in RPS, where a prefabricated structure is automatically disassembled and reconstructed according to a design change [11].

Škrjanc and Šubic describe the use of an Internal Model Control (IMC) system to control the CO2 levels of buildings depending on the occupancy fluctuations. The model is simulated in a gallery and the results show a successful achievement of desired air quality coupled with a decrease in operation costs in comparison to the typical air control system. This system is very advantageous in buildings where the occupancy-level fluctuations are high [12].

Bock and Linner (2015) suggest five management innovative techniques that are vital in implementing robotics within construction. These are robot-oriented design, robotic industrialization, construction robots, site automation, and ambient robotics [13].

1.2.6 Museum Requirements

Janeen Ault (2000) explains the required environmental factors in museums for the preservation of artifacts and the comfort of visitors. The author states that the main factors requiring consideration are humidity, temperature, light, pollution, and biological attack. Humidity and temperature changes can damage artifacts by causing them to expand or contract. If the artifacts' material is rigidly bound, mechanical failure may occur. Light in the infrared region may also cause severe damage through the dehydration of materials and its effect on their appearance and mechanical strength. Air pollution in the form of sulfur dioxide, oxides of nitrogen or ozone can discolor textiles and fabrics and weaken materials. Finally, biological attacks in the form of fungi and mold consume artifacts and weaken their material. The author tests these environmental factors inside the Field Museum and finds the control severely lacking. She suggests a renovation of the building's HVAC as a solution [3]. This study explains the environmental factors that must be considered in museum construction.

1.3 Statement of the Problem:

In *The future of construction automation: Technological disruption and the upcoming ubiquity of robotics*, Thomas Bock (2015) argues that the conventional construction method is slowly reaching its limits, and the need for a new automated one is arising.

The project aims to tackle automation specifically in museum construction. The choice of museums as the object of this study is due to the multitude of unique factors associated with these structures. First, the uniqueness of museums invites innovative architectural designs. These new designs include complex details, and hence require prefabrication for vast spans. This can be achieved using an automated system, saving time and easing adaptation to any design change. Secondly, museums have their own environmental specifications. This is because they accommodate large crowds and because they contain objects and collections of high value which must be preserved in a safe, healthy environment.

1.4 Significance of the Project

This project aims to introduce new concepts of automation into the construction and operation of museums. This would simplify and bridge the gap between automation and museum construction. By using museums as an example of a standard and well-defined structure that requires specific construction methods, automation implementation can be applied to other building types ranging from industrial factories and power plants to residential buildings and villa compounds.

As the conventional method reaches its limits, many of its fundamental problems such as low worker productivity, high accident rates, deteriorating quality, and shortage of skills [1], can be solved by automating the processes of construction one task at a time. Not only does this technology have the potential of increasing work safety and comfort, but it can also improve construction efficiency and quality while reducing the requirement for human intervention in the construction phase. If successfully implemented, automation tool kits would represent a leap in the industry, increasing efficiency and project potential.

1.5 Objective

The objective of this effort is to propose an automation toolkit for museum design, construction, and operation.

2 Automation Toolkit

This section presents a toolkit for automation in museum construction and operation. It is designed to be used when evaluating the level of automation in a particular project. The rating system that is used follows the Likert scale that ranges from 0 to 5, where 0 represents no level of automation and 5 represents full use of automation. Table (1) divides automation into two main stages: design and construction, and operation. Each stage contains multiple automation components. In turn, these components have a variety of applications, or automation subcomponents, which are also displayed in the table. Accordinly, each number on the Likert rating scale represents a degree of automation, or how extensively the automation subcomponents, as listed in table 1, are used in the museum. 0 indicates there is no automation used in the project, 1 indicates there is scarce use of automation, 2 means there is a poor use of automation, 3 means an average amount of automation is used, such that almost half of the project is automated, 4 shows the project uses a high percentage of automation, while 5 indicates there is a 100% effective use of automation. In the particular case of robotics, for example, a 0 rating would mean that there is no use of robotics in any task, a 5 rating would mean that robotics were used in every possible task they could perform (coating, painting, finding optimum sequence to design changes, using assembly by disassembly, and lifting/transporting the equipment) and a 3 rating would mean that robotics were used in approximately two out of the four tasks they are capable of performing. Table (2) illustrates the use of the automation toolkit rating scale for a hypothetical museum. If the hypothetical museum's implementation of automation was evaluated as shown in the example in table 2, its automation score would average to 3.24, which is considered an acceptable automation performance.

Table 1. Automation Toolkit Components

	Component	Use
	Building Information Modeling (BIM)	Risk Management
		Budget Maintenance

Design & Construction		Schedule Maintenance
		Quality Maintenance
		Energy &Carbon footprint Estimation
	3D Printing	Façade component Creation
	Robotics	Paint and Coating
		Optimum Design Change Sequence
		Assembly by Disassembly
		Lift/Transport Equipment
Operation	Internet of Things (IoT)	HVAC Optimization
		Information
	Holographic Display Cases	Object History
		Object Purpose
		Hidden Details
	Indoor Air Quality	Carbon Dioxide Monitoring
		Humidity and Temperature Control

Table 2. Automation Toolkit Scale Example

Automated		Likert Scale					Description
	0	1	2	3	4	5	
	No use	Scarce use	Low use	Acceptable	High use	Full use	
Risk Management			✔				Schedule, cost, and design change tracking
Budget Maintenance				✔			Earned value analysis
Schedule Maintenance					✔		Earned value analysis

Quality Maintenance		✔					BIM quality log
Energy &Carbon footprint Estimation			✔				BIM into Simapro
Façade component Creation	✔						3D printed designs
Paint and Coating						✔	STCR replacement of manual labor
Optimum Design Change Sequence						✔	Software in re-prefabrication
Assembly by Disassembly						✔	Hardware in re-prefabrication
Lift/Transport Equipment				✔			STCR
HVAC Optimization				✔			Energy saving system
Information					✔		Holographic guides
Object History					✔		Holographic display cases
Object Purpose				✔			Holographic display cases
Hidden Details				✔			Holographic display cases
Carbon Dioxide Monitoring					✔		Air quality control
Humidity and Temperature Control					✔		Air quality control

3 Discussion

Based on techniques investigated in previous studies, a multitude of automated construction and operation components are chosen and customized to create an automation toolkit that best fits the requirements of modern museums.

The first step for customizing automated construction and operation methods for museums is to collect information through research on existing automation methods and their requirements. Additionally, information about the specific requirements of museums such as safety, indoor air quality, and visitor comfort and entertainment must be acquired. The next step is to choose the most suitable automation approaches that meet museum requirements depending on cost, efficiency, and sustainability. The final step is to understand how the chosen automation methods complement each other and how they can be applied together to produce the most efficient and effective model in construction and operation.

4 Conclusions

Automation can be applied in the design, construction and operation stages of any museum. Due to the current limitations within the conventional method, automation has become an inevitable necessity. It offers various benefits and can save time, energy, and cost if utilized properly. The presented automation toolkit is designed such that it can be used to evaluate the level of automation in any project. The components chosen were based on the optimal level of automation, rather than the maximum one. In other words, the automation methods were selected according to the optimal levels of cost, time, and energy. As previously mentioned, labor costs can be reduced up to 40% when using automation. Automation also minimizes labor transportation thereby saving energy. The energy recovery wheel within the HVAC system can save energy as well. Finally, STCRs save time by 37.5%. Time efficiency is also increased due to the use of IoT and holograms in operation.

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