Automation in Construction 67 (2016) 31–47

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Review

Analytical review and evaluation of civil information modeling

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A R T I C L E I N F O

Article history:
Received 21 May 2015
Received in revised form 13 January 2016
Accepted 14 February 2016
Available online 6 April 2016

Keywords:
Adoption evaluation
Building information modeling (BIM)
Civil information modeling (CIM)
Civil infrastructure

A B S T R A C T

Building information modeling (BIM) has been widely adopted in the building industry. However, the use of BIM in civil infrastructure facilities, sometimes referred to as civil information modeling (CIM) has been slow in its application. Industry and academia are increasingly putting effort into CIM study and implementation, but so far there has been no comprehensive review of their effort in this regard. This paper presents a framework to evaluate the current practices of CIM adoption for various civil infrastructure facilities. In this study, civil infrastructure facilities were divided into nine categories for evaluation and the effort with regard to CIM adoption for each civil infrastructure category was evaluated in six aspects. Based on the evaluation and comparison results of 171 case studies and 62 academic papers on CIM, research gaps were identified and recommendations were made. For example, the findings show that data schema development for civil infrastructure facilities other than bridges, roads, and tunnels are lacking. The results and research gaps revealed by this study are useful for both researchers and practitioners.

Contents

1. Introduction

Building information modeling (BIM) is a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout

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http://dx.doi.org/10.1016/j.autcon.2016.02.006
0926-5805/

a building life-cycle" [1]. BIM, which enables a facility to be digitally represented by object-based modeling, not only changes how a facility is created from traditional CAD solutions, but also remarkably alters the key delivery processes involved in constructing a facility. Therefore, BIM is not only a technology change, but also a process change. Since its inception in the 1970s, BIM has gradually transformed the way that we work in the architecture, engineering and construction (AEC) industry. For example, BIM has changed the traditional way of conveying design intent from adding symbols and human interpretation on drawings, to being represented by intelligent objects that carry detailed information which can accelerate the design, procurement and construction process. BIM was first introduced to building projects to facilitate complex systems and has achieved wide penetration in the building market [2]. Successful BIM implementation on buildings has reaped the rewards of lower cost and higher productivity, accuracy, communication and efficiency in the building market [2]. Since civil infrastructure projects are often large projects involving huge capital investment and intricate stakeholder relationships, it is especially important to integrate all the information and data analysis for better design, better construction and better operation for these complex structures. While some people think that BIM can only be used for building projects, many people argue that a "building" in BIM is only a verb referring to the building process, not a structure, and therefore BIM can also be adopted for civil infrastructure projects to improve the project delivery. The *SmartMarket Report* [2] published by McGraw Hill Construction revealed that the success of BIM in regard to buildings increases the likelihood of the use of BIM for civil infrastructure facilities. Therefore, the application of BIM in civil infrastructure facilities may be adopted at a more rapid rate than when it was introduced for buildings.

Civil information modeling (CIM) is a term commonly used in the AEC industry to refer to the application of BIM for civil infrastructure facilities, such as bridges and tunnels. As CIM is a term recently introduced by many researchers and practitioners, various institutions have different definitions of CIM, such as "civil integrated management" [3], "construction information modeling" [4], and "construction information management" [5]. Other terms such as "Horizontal BIM" and "Heavy BIM" are also used to represent BIM for civil infrastructure [2]. In this paper, the term "civil information modeling" (CIM) is used to denote the application of BIM-based technologies for non-building civil infrastructure projects.

There are three main differences between BIM and CIM that should be identified before applying BIM to civil infrastructure projects. Firstly, the structure and components of buildings are different from those of civil infrastructure facilities. For example, bridge decks contain shear pockets which do not exist in buildings, whereas buildings contain windows which do not exist in roads. In addition, once the foundations of a building are confirmed, the surrounding geometrical environment has little impact on the construction of the building [2]. However, civil infrastructure projects are subject to every nuance of the terrain. Therefore, building projects are also called "vertical projects", while civil infrastructure projects are usually called "horizontal projects". Secondly, the terminology to represent buildings and civil infrastructure facilities is different, partially due to the difference in the structure and components. For example, the vertical structural supports in buildings are called "columns" while those in bridges are called "piers". Therefore, data schemas for buildings cannot be directly used for civil infrastructure facilities. Finally, BIM and CIM have different modeling methodologies. For civil infrastructure facilities like roads and bridges, all the specific entities are placed horizontally relative to the axis or the reference line. People also model civil infrastructure facilities by defining the cross sections and then extending them horizontally along designated alignments. On the other hand, BIM is often created vertically floor by floor. Apart from these differences, the data management and exchange of BIM and CIM are similar.

As BIM has achieved wide adoption in the building industry, increasing effort has been put into CIM. Some scholars have explored various possible uses of BIM for civil infrastructure facilities. For example, Cho et al. [6] proposed a holistic BIM library system which contains the geometry, properties and product information based on parametric modeling for efficient quantity takeoffs of tunnels constructed using the New Austrian Tunneling method (NATM). Yabuki [7] discussed the issues and obstacles of BIM for civil infrastructure and proposed possible methods to implement BIM in the civil infrastructure domain. Even in the AEC industry, companies worldwide have utilized BIM technology for various civil infrastructure projects. For example, Breijn [8] used Autodesk BIM solutions to help leverage existing GIS and survey data to design and simulate construction of a replacement railroad bridge. Clash detection and 4D schedule simulation were also undertaken for the bridge [8].

BIM is gradually changing the way we design, construct, and manage civil infrastructure facilities. However, currently no single study comprehensively evaluates and compares the application of BIM for various civil infrastructure facilities. Such a study could help understand the current trends of BIM adoption for civil infrastructure globally and identify the research gaps. Therefore, this paper aims to (1) provide an analytical review of the current BIM adoption for various types of civil infrastructure facilities, (2) evaluate the current practices and maturity of CIM development, and (3) identify the gaps in CIM development and adoption. This paper consists of six sections. In Section 2, the categorization of civil infrastructure facilities is presented, and 13 types of civil infrastructure under five domains are summarized. They are further grouped into nine categories for evaluation: (I) bridges, (II) roads, (III) railways, (IV) tunnels, (V) airports, ports and harbors, (VI) energy infrastructure, (VII) utility infrastructure, (VIII) recreational facility infrastructure, and (IX) water management infrastructure. Section 3 presents an evaluation framework to assess the current practices and maturity of CIM in each civil infrastructure category. Section 4 discusses the evaluation results. Based on the evaluation results and the comparison among different civil infrastructure categories, research gaps are identified and recommendations are given in Section 5. Section 6 concludes the paper.

2. Categorization of civil infrastructure facilities

There is no universal categorization of civil infrastructure facilities. Different organizations in various countries have different categorization methods and terminologies for civil infrastructure facilities. With reference to the categorizations used by McGraw-Hill [2], Bentley [9], Halpin [10], and others, all major kinds of civil infrastructure facilities are classified into 13 types under five domains, as shown in Table 1 and listed below:

- *Transportation infrastructure*, including (1) bridges, (2) roads, (3) railways, (4) tunnels, (5) airports, and (6) ports and harbors.

Table 1
Categorization of civil infrastructure facilities.

Categories of civil infrastructure			Domains
I	1)	Bridges	Transportation infrastructure
II	2)	Roads	
III	3)	Railways	
IV	4)	Tunnels	
V	5)	Airports	
	6)	Ports and harbors	
VI	7)	Power generation	Energy infrastructure
	8)	Oil and gas	
	9)	Mine	
VII	10)	Utility	Utility infrastructure
VIII	11)	Recreational facilities	Recreational facility infrastructure
IX	12)	Water and wastewater facilities	Water management infrastructure
	13)	Dams, canals and levees	