Advanced Engineering Informatics 27 (2013) 378–385

Contents lists available at SciVerse ScienceDirect

Advanced Engineering Informatics

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

A semiotic framework to understand how signs in construction process simulations convey information

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ARTICLE INFO

Article history:
Received 23 August 2012
Received in revised form 21 February 2013
Accepted 3 April 2013
Available online 29 April 2013

Keywords:
4D CAD
Visualization
Semiotics
Building information modeling
Construction planning
Construction scheduling

ABSTRACT

Planning the production sequence for a construction project requires the combination and transfer of information and knowledge from a large variety of areas. To support this knowledge combination and transfer, construction process visualizations, also referred to as 4D CAD, have proven to be valuable tools. Within these visualizations, signs, such as icons, indexes, or symbols, are often used to visualize contextual information related to the different construction activities. To understand the mechanisms of how these signs meaningfully convey such contextual information, this paper introduces a semiotic framework consisting of semiotic concepts, their definitions and relations. This paper also illustrates the power of the framework by applying it for analyzing the signs used in two construction process visualizations.

1. Introduction

During the engineering design process, planning for the final assembly of the product is an intrinsically knowledge intensive task. This is, in particular, true for planning the assembly of a construction product because of two distinct characteristics of these products. For one, construction products are immobile and have to be assembled at a specific location. This involves that engineers need to account for the local conditions while planning how to best assemble the product. Additionally, construction products are assembled by a team of different "co-creating" companies whose operations need to be coordinated in space and time. The sound development of assembly plans for a construction product requires the combination of technically and locally specific knowledge from different engineering and non-engineering areas.

Empirical case research has shown that this required knowledge transfer can be supported by construction process visualizations, often also referred to as 4D CAD (see for example [1–3]). However, beside a large number of case studies that indicated the practical value of construction process visualizations, little research has developed concise theoretical frameworks that allow researchers and practitioners to understand the underlying principles that make these visualizations so powerful. To further theoretical understanding in this area, this paper introduces a framework that combines several semiotic concepts with the goal to improve understanding of how these visualizations convey contextual meaning. To illustrate the power of the framework, the paper also presents the results of an application of the framework to analyze two exemplary construction process visualizations that were successfully used by practitioners.

The paper is structured as follows: After a more in depth introduction of construction process visualization research, the paper introduces a number of principles from visual semiotics and combines them into the semiotic framework to describe general mechanisms of how signs in construction process visualizations transfer contextual meaning. The paper then illustrates the explanatory power of the framework by analyzing two construction process visualizations that have been successfully used to support planning practice. The paper closes with a discussion of the theoretical and practical implications.

2. 4D construction process visualizations

Construction process visualizations, or 4D CAD models, are defined as the integrated visualization of 3D CAD engineering data and construction schedules with purpose built modeling technology [4–6,2]. In recent years, a myriad of studies have explored the practical applicability of construction process visualizations for marketing and communication purposes, design review, cost estimating, bid preparation and procurement [2], constructability review [1], site management [7], scheduling, work-flow-based or location-based planning [6], or the identification and resolution

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http://dx.doi.org/10.1016/j.aei.2013.04.001

of time–space conflicts [6]. Researchers have also developed methods of how to combine such construction process simulations with other construction management methods, such as the line of balance method [6] or discrete event simulations of construction activities [8]. Overall, the advantages of construction process visualizations have been documented well [4,2]. For instance, process visualizations support planners with identifying potential problems before actual construction starts. It has also been shown that construction process visualizations, for example, additionally allow for a more intuitive comprehension of the construction process than the traditional used two-dimensional drawings.

Common among most of the existing studies is that they describe construction process simulations that not only visualize the assembly sequence itself, but also contextual information. Some noteworthy examples of such contextual visualizations are the display of construction machinery paths using lines [9–11], the use of blocks to describe surrounding buildings [12], the use of grids to allow for a better spatial orientation [13], the display of work zones and spaces using surfaces [14–16], or the display of passenger routes [1]. Despite this widespread integration of contextual information in construction process visualizations, few studies have specifically focused on exploring this feature. For the most part, the research community still lacks a systematic way for evaluating and analyzing mechanisms for how to meaningfully convey contextual information in construction process visualizations. To overcome this shortcoming, we developed a semiotic framework that introduces, defines, and relates principles from visual semiotics, the theory of how visual signs can be used to convey information. The next section introduces visual semiotics and describes the semiotic framework.

3. A semiotic framework to understand how signs convey context related information in construction process visualizations

Semiotics is the study of signs and their use to convey social meaning [17]. Semiotics has been applied in many different fields, but important in the context of this paper are the two fields of visual semiotics [18] and computer semiotics [17]. The field visual semiotics is concerned with how pictures can convey meaning, while computer semiotics is concerned with how computers can do so.

According to computer semiotic theory, every construction process simulation can be analyzed as a semiotic system. The main objective of generating such visualizations is to convey information about the planned processes of how to best assemble a physical facility, such as a building, a road, or a bridge. To this end, construction process visualizations then signify information about a planned assembly process by rendering three-dimensional representations of physical objects that they hide, display, and highlight.

Within construction process visualizations additional signs can be used to convey meaning about context related information. According to semiotic theory, these signs can be categorized in three groups according to how they allow for comprehension: icons, indexes, and symbols [19]. Icons try to represent the signified by similarity. Or in other words, icons work by imitating some visual feature of the object that is to be represented. Indexes try to convey some relationship between the signifier and the signified which is often of a spatial nature [20,21]. As a final category of signs, symbols operate not by using visual or conceptual connections to the signified, but through a socially established convention, i.e. something that has to be learned before the meaning of the symbol can be understood. Many traffic signs are, for example, symbols in that they bear no relationship with what they symbolize and operate simply through previously learned conventions. Such symbols can then only be understood by recalling this convention [22]. One widely applied technique to allow conveying meaning in construction process visualizations by relying on recall abilities is, for example, the use of colors to depict construction activity types, such as construction activities or demolition activities [23]. Obviously, colors can also be used to convey contextual information within construction process visualizations.

Important information that is conveyed with construction visualizations is related to the time a certain event occurs. This meaning can be conveyed by displaying a specific sign for a certain duration of the construction process simulation [17]. Such transient behavior is one of the main mechanisms to convey meaning in construction process visualizations. Again, transient mechanisms are similarly useful to convey meaning with signs signifying contextual information.

Closely related to the transient or permanent character of a sign, another important characteristic of signs is how well they can be detected [24,17,25]. This is important as construction process visualizations, particular those that also represent contextual information, are usually cluttered with a large number of signs. The possibilities to detect a specific sign within such cluttered visualizations is mainly related to how the sign is positioned in space, the shape of the sign, the sign's color [22], and the above introduced transient or permanent behavior of the sign [17]. For example, transient signs that are displayed only at a certain time are easily recognizable in the center of the visualization, but can be easily overlooked in the visualization's periphery. At the same time, non-transient signs, that appear throughout the duration of the visualization, are harder to detect at first, but the chance that they are detected with the ongoing duration of the visualization increases [17].

In summary, signs to convey contextual information can be categorized differently according to how they convey meaning and how they can be detected. Table 1 summarizes the different characteristics of signs we derived from semiotic theory within a holistic theoretical framework. By combining the different concepts introduced above, this semiotic framework can describe the underlying mechanisms of how signs used in construction process visualizations convey contextual information. To show the power of this derived semiotic framework, the next section discusses the use of signs in two illustrative process visualizations using the framework's categories.

4. Illustrative application of the semiotic framework

To provide evidence for the analytical power of the framework, we chose two construction process visualizations that were accessible to us and that had the purpose to additionally convey contextual information—one visualization with the purpose to convey information about project risks and another visualization with the purpose to allow for a better understanding of the impact of hospital construction work on patient safety. The visualizations were generated by professional modelers and subsequently used by project managers working on construction projects. We had easy access to the visualizations because students from the institution of the authors of this paper supported their generation and use. Through this direct involvement, we became familiar with the information that these signs were designed to convey and, hence, we were meaningfully able to analyze the mechanisms of how signs used in the visualizations conveyed meaning.

We started to analyze the established models by thoroughly reviewing the visualizations, extracting all signs used to convey contextual information. Using this list of identified objects we then used the semiotic framework to categorize the signs into icons, indexes, or symbols. The categorization was done in close discussion