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

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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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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

Table 1
Semiotic framework to analyze and understand the use of signs to convey contextual information in construction process visualizations.

Type	Icon	Index	Symbol
Conveys meaning by	Similarity	Relation	Recall/convention
Temporal behavior	Transient/non-transient		
Allows detection by	Color, size, placement, transient behavior		

among the two authors of the paper. After categorization, we then analyzed how the used signs conveyed meaning using the other sign categories of the framework. The next section introduces the two cases in more detail and presents the results of the above described semiotic analysis of the process simulations.

4.1. Representing risk information

The first process visualization, was concerned with the integration of project risk related information for a large mega project in the Netherlands. On this project a formal risk management procedure was introduced following generally accepted risk management practice. In a number of risk identification sessions, different practitioners developed a register with possible risks that might occur during the execution of the project. This register was then stored in a spreadsheet file and distributed in the form of a risk table to the planning practitioners of the project.

Because of the large number of risks in the register and the spatial and temporal distribution of the risks practitioners on the project struggled with clearly understanding when and where a certain risk might occur. This lack of understanding, in turn, hindered the practitioners in their efforts to develop appropriate risk mitigation measures. To overcome this problem, the risk managers decided to explore the possibilities construction process visualizations offer to support risk mitigation tasks. To this end, the project team developed a construction process visualization that integrated several signs to represent risk specific contextual information and used the visualization in one risk mitigation meeting. Fig. 1 shows a number of frames from this process visualization and Fig. 2 summarize the signs used within the visualization to convey contextual meaning. The next paragraphs will describe these signs in detail.

The first example represented in the Fig. 2a uses three dimensional cubic objects to signify the location of important temporary buildings with a public or commercial function (for example train-ticket sales counters or a fast-food restaurant) on and around the construction site that might be negatively affected by construction work. These signs were color-coded blue, because blue had been previously conventionalized on this project for the representation of buildings with a commercial function. In fact, the walls of these temporary buildings actually were blue on the physical construction site.

Fig. 2b illustrates the additional use of text to support the recognition of specific buildings within the model. The specific building represented in the figure hosted a multitude of important firms and hence planners had to ensure that no damage occurred to this building during the construction activities. Additionally, the building represented an important landmark in the area of the construction activities and, hence, served as an important point of reference to understand the spatial relations in the process visualization better. However, within the construction process visualization the mere geometric shape of the specific building was not sufficient for all users to directly recognize it. Hence, the modelers on this project marked the visual representation of the building with the three letters G.H.G. that stand for ''Groot Handelsgebouw'', which are the Dutch words for 'Large Trade Building'.

Fig. 2c illustrates the use of cubic three-dimensional objects to signify the reserved space for the allocated public pedestrian routes. Ensuring the safety of public pedestrians throughout the construction work was one of the most important objectives during the planning activities on this project. To understand possible risks to pedestrians, planners, hence, had to understand which construction activities were planned close to allocated pedestrian areas. The integration of the cubic objects into the visualization of the construction process allowed for such an easy understanding.

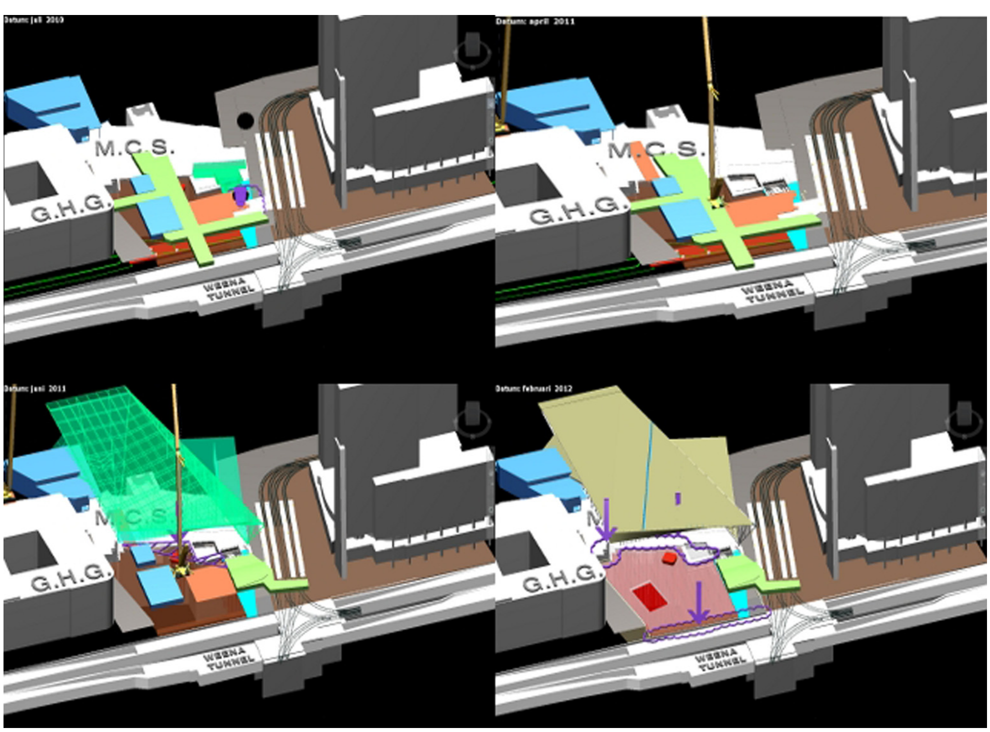

Fig. 1. Selected frames from the construction process visualization of the first illustrative case project.

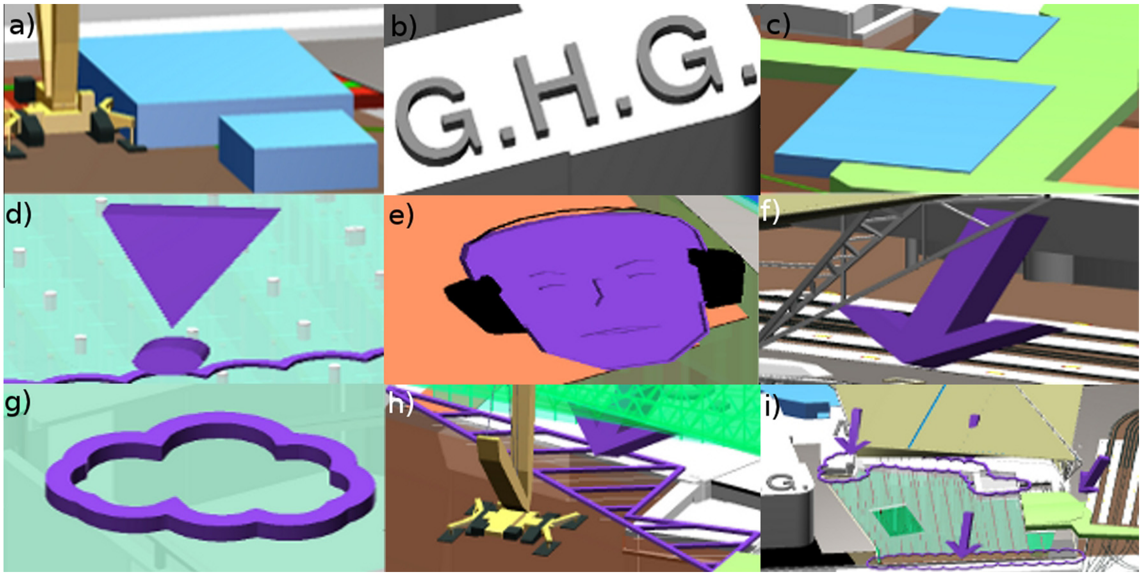

Fig. 2. Signs used on the first illustrative case project to signify risk related information. From left to right, top to bottom: Use of cubic geometry to signify public buildings (a), use of text to signify the type of a building represented with cubic geometry (b), use of cubic geometric objects to represent space reserved for pedestrian traffic (c), use of an exclamation mark to signify the general occurrence of a risk (d), use of a conventional symbol to signify possibilities for negative impact through construction noise (e), use of an arrow to signify the location of a risk (f), use of a cloud and a hatched area to signify a potentially risky area (g and h), and the use of different signs in combination (i).

The visualization used exclamation marks to represent general important risks that were recorded in the risk register (Fig. 2d). These signs were implemented as transient objects that would only appear during the expected duration of a risk. Along the same lines, but more specific, the visualization signified risks related to possible negative impacts of noisy construction by using a conventional symbol (Fig. 2e). This icon represents a human head wearing a hearing protector which is a generally acknowledged symbol to represent health hazards caused by industrial noise (see for example [26, p. 141]). Again this sign was used transiently, e.g. it only appeared at the relative time in the visualization the risk was expected.

Another type of transient object used were arrows. Compared with the other two transient objects described earlier in this paragraph, arrows have the added advantage that they make the location a risk is expected to occur more explicit (Fig. 2f). As an example, the visualization specialist used arrows to point to locations where water leakages into excavation pits were most likely to be expected during a certain period of construction. Because arrows convey meaning through a spatial relation they can be semiotically best described as indexes.

To indicate extended areas that might be possibly affected by a risk, the visualization used two different signs (Fig. 2g and h). For one, ''risky'' areas were signified using objects representing clouds. Cloud objects are conventionally accepted signs to roughly signify changes in construction drawings. As such, construction practitioners were already familiar with this sign. Additionally, the visualization specialist used hatched surfaces to more accurately signify ''risky'' areas. Again this representation corresponds to accepted conventions often used in construction drawings. Again both signs were used transient, i.e. only being displayed in the process visualization at the times a certain risk was expected.

To offer the reader an impression of how this specific construction process visualization used different signs in combination, the lower right illustration in Fig. 2i shows an example of the use of some of the above described transient signs in composition.

4.2. Representing patient safety information

The second process visualization we analyzed was concerned with the integration of patient safety related information to plan for the renovation of a hospital in the Netherlands. On this project, the administration of the hospital tried to evaluate together with the project's architect whether it was feasible to maintain surgical arenas operational during the re-construction activities. In a number of meetings, hospital staff and architects developed a staging plan for the planned construction activities. Initially, marked-up two dimensional drawings were used during these meetings. Soon, however, the participants of the planning effort realized that the 2D drawings did not help to understand the transition between phases well. Because of the importance of planning these transitions in a safe manner, the participants decided to use construction process visualizations to support their discussions.

On this project, the project team first established an initial process visualization using the available marked-up sequence drawings showing the different possible construction phasing options. Based on this initial visualization, the team then integrated patient safety information. Subsequently, the team used this process visualization in a number of meetings to discuss ways of how to best stage the construction sequence. Fig. 3 provides an impression of this process visualization in the form of a number of frames from the visualization showing different planned construction stages. In what follows, we will describe the signs used in the final version of the visualization. Fig. 4 provides an overview about these signs.

The first example represented in Fig. 4a displays an overview of the construction process visualization that illustrates how the routing of hospital professionals, patients, and organic hospital waste around an ongoing operating room was visualized. Different types of signs are combined for the visualization of the relevant processes in order to enable a meaningful discussion between construction professionals (the architect and the constructor), medical staff, and infection safety specialists. For example, Fig. 4b shows how the rooms that host vulnerable ongoing hospital processes are indicated using a semi-transparent orange surface object. Further, Fig. 4c shows a detail of a text based sign. This sign was included to convey the sterility-status of the corresponding room – a pivotal condition that has to be guaranteed to allow ongoing hospital processes.

Complementing these text based signs, specific routes were indicated using arrays. For example the sterile route of patients into operating rooms is represented by arrows that point into these

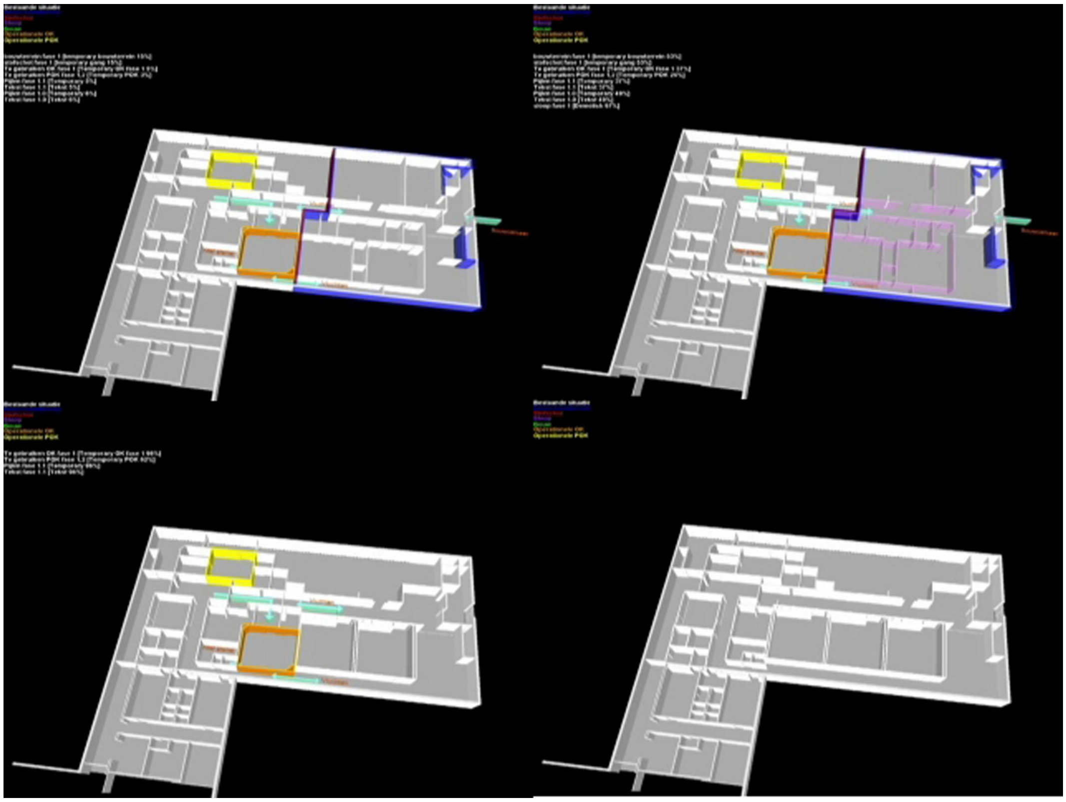

Fig. 3. Selected frames from the construction process visualization representing different planned phases of the hospital renovation.

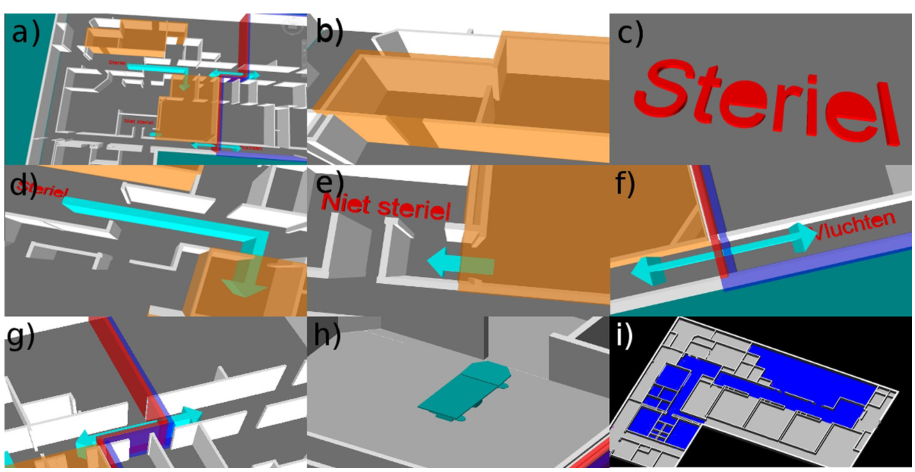

Fig. 4. Signs used on the second case project to signify patient safety related information. From left to right, top to bottom: a snapshot showing an overview of how routing was visualized by different signs in combination (a), the use of semi-transparent orange fill to represent vulnerable rooms (b), the use of textual information (c), the use of a combination of textual information and a 3D arrow to represent specific routing related to the operating room, such as an ingoing sterile route (d), an outgoing non-sterile route (e), and escape routing (f), the use of red walls to indicate dust barriers (g), the use of an operating bed object as reference-point within the model (h), and the use of floor surface colors to indicate air-pressure zones (i). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

rooms (Fig. 4d). In a similar manner, the out-going route of organic hospital waste is visualized by arrows pointing from a specific space to the outside of the space (Fig. 4e). Additionally, escape routes were indicated with an arrow pointing in two directions (Fig. 4f).

How dust spreads through a building during construction is a second important planning activity for hospital renovations. Hospital acquired infections are a major problem during renovations because of the spread of spores and mold with dust created by construction activities. The main measure to prevent the spread of dust during construction and renovation activities are dust barriers that isolate areas with ongoing construction work from areas with ongoing medical processes. Fig. 4g, shows how the planned location of dust barriers is represented in the construction visualization by using color-coded vertical surfaces.

Further, the visualization used the symbol of a bed to signify operational surgery arenas (Fig. 4h). This sign was needed because the planned locations of interior walls during the renovation would change frequently. Hence, it was not easy to quickly understand which rooms are operational and which not at a specific time within the process visualization. Finally, this specific process visualization also conveyed information about the pressure level of different areas. In hospitals, the pressure level is predefined on a room basis to avoid the spreading of germs. For example, sterile surgical rooms must have a higher air pressure level than hallways. The visualization signified different pressure levels by including colored horizontal surfaces into the 4D model (Fig. 4i).

The upper left illustration in Fig. 4a again shows a combination of the different signs used. All in all, this second illustrative example shows the use of signs within construction process simulations for a quite different purpose than in the first example. Together both examples show the breadth of possibilities to convey contextual information in process visualizations. In what follows, we will analyze the two above described process simulations using the introduced semiotic framework.

4.3. Using the framework's concepts to analyze how the signs conveyed meaning

Tables 2 and 3 provide a categorization of the above described signs. The tables use the framework to summarize how the signs within the two process visualizations convey meaning and allow for easy detection.

A closer look at the two tables shows that the first case used mainly symbols to convey risk related meaning, while the second case relied upon a mixture of icons and symbols. An analysis using the introduced framework might help to meaningfully discuss, if not even understand, the rationals behind the respective choices of the modelers on these two cases. In the risk case, the conveyed contextual information was much less related to physical objects, but rather to locations on the construction site. In contrary, on the hospital case, much of the contextual information could be directly related to physical objects, such as dust barriers, or spatial categories, such as pathways or operation theaters. Another reason for why the modelers on the two projects chose to use quite different sign types might have been related to the different audiences for which the respective process visualizations were intended. In the first case, the audience for the visualizations were mainly construction professionals. On the health safety case, the audience was from a much larger variety of different backgrounds, comprised of construction professionals, hospital administration staff, or medical professionals. This mixed audience might have made the use of more icons a more adequate tool to convey contextual meaning.

The risk visualization case shows how existing conventions, stemming from a rich tradition of the use of signs in construction drawings, can provide a powerful technique to convey meaning in construction visualizations. Interesting here is that some signs used on construction drawings have been stripped of their initial meaning. This, in particular, holds for the cloud objects used. In traditional construction drawings, clouds signify changes in the design from one version to the other. In the risk process visualizations clouds were merely used to signify a specific area that is subject to possible high risk during the planned construction work. Because clouds represent symbols and symbols convey meaning through conventions that have to be learned by recipients, the cloud objects might have actually been, to a certain extent, confusing for practitioners on the project. Our project observations, however, also show that practitioners found the more conventional warning sign as least visible in this rather cluttered construction process visualization, while 3D arrows and the clouds were perceived as the more detectable indicator for project risks. This might have been the reason to use the cloud objects for a different purpose than in traditional construction drawing.

The second case shows less reliance on conventions to convey meaning and applies other means, such as similarity, color coding, and recall. Again this apparent difference in how the modelers built the two visualizations could be caused by the different audiences the visualizations were targeted for. In the second case the audience came from a much more diverse professional background, hence, viewers might not have a shared understanding of conventions. However, our observations of the use of the 4D model on this project also showed that less reliance on conventions might also lead to disambiguities in how different users of the visualizations interpreted the signs. For example, on this project the architect found color coding to be "an effective way to visualize the temporal dimension of project plans" and to be "useful to put emphasis on a particular point of the plan". At the same time, the communication advisor of the hospital criticized the color coding because the visualization "contained too much different colors". The analysis shows that the introduced framework can help to draw attention to such ambiguities caused by the reliance on representing contextual information by using non-conventional signs. The experience on the second project also showed that the use of textual signs is a good alternative to support the communication of contextual information between groups that have little established conventions on how to use signs. On the hospital project, both the architect and the hospital staff mentions the usefulness of text, in particular, to convey meaning about information about routes for construction workers, medical staff, and patients.

It is not surprising that both projects mainly used transient signs to convey contextual information, after all, one of the main reasons to create construction visualizations is to show how construction activities and related contextual information transition over time according to a planned construction sequence. Nevertheless, both projects applied non-transient signs to signify permanent risks or threats to patient safety. Hence, both, transient and non-transient signs, are important vehicles to convey contextual information.

Along the same lines, non-transient behavior also provides a powerful mean to allow for the easy detection of signs in the often cluttered construction process visualizations. However, as mentioned in the theoretical section of this paper, the use of non-transient behavior to support detection only works in the center of the process visualizations. Non-transient signs in the periphery might easily be overlooked as they tend to blend in with the cluttered background. This also reflects our observations of how practitio-

Table 2
Semiotic categorization of the signs used to signify risk related information (The table refers to Fig. 2).

Sign	Type	Conveys meaning	Transient	Allows detection
Fig. 2a	Icon	Similarity, color	No	Non-transient behavior, color
Fig. 2b	Symbol (text)	Convention	No	Non-transient behavior
Fig. 2c	Symbol	Recall, color	No	Non-transient behavior, color
Fig. 2d	Symbol	Convention	Yes	Color, size
Fig. 2e	Symbol	Convention	Yes	Color, size
Fig. 2f	Index	Convention	Yes	Color, size
Fig. 2g	Symbol	Convention	Yes	Color
Fig. 2h	Symbol	Convention	Yes	Color

Table 3
Semiotic categorization of the signs used to signify patient safety related information (The table refers to Fig. 4).

Sign	Type	Conveys meaning	Transient	Allows detection
Fig. 4b	Icon	Similarity, color	No	Non-transient behavior, color
Fig. 4c	Symbol (text)	Convention	Yes	Non-transient behavior
Fig. 4d–f	Symbol, index	Convention	Yes	Color
Fig. 4g	Icon	Color	Yes	Color
Fig. 4h	Icon	Recall	Yes	Central placement
Fig. 4i	Symbol	Convention	Yes	Color, size

ners used the 4D risk model. Because this model was in general already quite cluttered, some non-transient signs blended in with the presented design information shown in the visualization. One technique applied in the risk case to overcome this problem was to make signs relatively large with respect to the construction activity related objects.

5. Discussion

The above analysis of the used signs in the two cases provides evidence for the power of the introduced framework. By combining semiotic concepts, the framework allowed for the meaningful discussion and analysis of how contextual information can be conveyed through construction process simulations.

With the power to explain how signs convey meaning the framework is useful for at least three different audiences. For one, the framework can help researchers to develop generally applicable signs that can be used in construction process simulations across a wide range of application areas and cultures. Similar to worldwide accepted signs in construction drawings, such as clouds or different types of hatches [26], we envision that future research to develop standardized signs to be used in construction process visualizations could be supported with the framework.

Additionally, the framework can support modelers whose task it is to generate project specific construction process visualizations. The two above examples, represent purposeful visualizations for very specific contexts. Next to using general purpose signs, construction process visualization modelers will always need to design specific signs that convey contextual meaning important in specific project contexts. The framework can help modelers with this task.

Finally, the framework will be helpful for construction planners that intend to support their knowledge intensive planning tasks with construction process visualizations that also convey contextual meaning. By better understanding the mechanisms of how signs can convey contextual meaning, we expect that project managers will be able to better and easier understand process visualizations.

Overall, by supporting the above three target groups, the presented framework can help to improve the ways construction professionals will be able to model contextual information, and, in turn, convey this information better to different project participants. By providing concepts to understand and describe different sign characteristics, the framework can support the above described audiences to understand and communicate better how signs on a case to case basis convey or do not convey meaning. Such better understanding can then help to, for example, support new team members with learning the conventions of signs used in specific construction process visualizations or develop general training programs for modelers and project managers. Another example of how the framework can help is to judge the efforts of individual visualization modelers better. It is likely that modelers are biased by preferences and opinions. The concepts of the framework will allow to discuss these preferences and opinions in a meaningful way and understand rationals of why a modeler chooses a specific sign option. Finally, the better possibilities to communicate how signs work could along the same lines, for example, help to develop project specific sign dictionaries.

For the most part, the presented analysis can provide a first start to show how well the semiotic framework can describe the mechanisms of how signs convey contextual information. Nevertheless, one of the problems of the presented study is the reliance on only two exemplary cases of construction process visualizations. To allow for a more in depth understanding, future studies are required that use the presented framework to analyze a wide range of different signs used in process visualizations. In this way, these studies can provide more evidence for the power of the framework and can adjust the framework where needed. These studies are also required to empirically test to what extent signs are able to convey information to different audiences. The studies could be designed similar to other semiotic research efforts in other areas, such as in the study of the effects of traffic signs [27], during which several ways to signify information are tested on human subjects. We believe that the here presented study can provide a sound starting point for such future research endeavors. Future empirical studies can benefit from the analytical power of the here presented semiotic framework. In that, the framework can provide an important stepping stone for more empirical semiotic studies along the lines described above.

6. Conclusion

In 2011, Cerovsek wrote that "too much effort is currently expended on the subject of communication rather than on the semiotics of communication" [28]. We could not agree more with this statement. At its core, models representing building information are semiotic tools to support the communication of practitioners and the information exchange between computer applications. Hence, building information models should be analyzed using semiotic theories. Following this general call of Cerovsek, this paper introduced a framework derived from computer and visual semiotics to support practitioners and researchers to understand how construction process visualizations can convey contextual information. The paper also exemplary illustrated the applicability of the framework by using it to analyze two construction process simulations that have been meaningfully applied in the past. Next to showing the applicability of the framework, the theoretical analysis of the different signs used in the two process simulations are in themselves valuable guidelines for practical efforts that would like to use signs to represent contextual information in process visualizations.

In summary, the introduced framework with its concepts and their relations increases possibilities to understand and communicate the working of signs in construction process visualizations. Such better understanding, in turn, can lead to ways of how the complex decision making tasks during construction planning can be better supported with construction process visualizations. Besides these direct contributions of the paper, we see the presented work also as a first starting point for more studies in the semiotics of construction process visualizations, in particular, and all other building information model based tools, in general.

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