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Measuring the potential of augmented reality in civil engineering

Sebastjan Meža, Žiga Turk, Matevž Dolenc*

Chair of Construction Informatics, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Jamova 2, 1000 Ljubljana, Slovenia

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ABSTRACT

Recently building information models have substantially improved the explicit semantic content of design information. Information models are used to integrate the initial phases of project development. On the construction site, however, the designs are still mostly represented as line-based paper drawings or projections on portable displays. A generic technology that can integrate information and situate it in time, place and context is augmented reality. The specific research issues addressed are (1) does augmented reality have a potential use in civil engineering, (2) how big – in comparison to other technologies - is this potential and (3) what are the main barriers to its adoption. The generic research issue was to develop a methodology for evaluation of potentials of technology. A prototype was built. It was tested on a real construction site to evaluate the potential of its use using the action-research method. A set of structured interviews with potential users was then conducted to compare the prototype to conventional presentation methods. Using this methodology it has been found out that augmented reality is expected to be as big a step as the transition from 2D line drawings to photorealistic 3D projections. The main barrier to the adoption is immature core virtual reality technology, conservative nature of construction businesses and size of building information models.

1. Introduction

Tools for designing in construction have evolved through history. Pens, pencils and paper have been replaced with CAD (computer aided design) and BIM (building information modelling) software. Engineers, builders, planners and contractors also use various domain specific software to support their work. A priority for construction informatics research and practice has been to effectively integrate the construction processes using information technology [12]. Adequate standards, e.g. Industry Foundation Classes (IFC), have the potential of solving the problem of interoperability of software and representation of information in designing [15].

While the design phase is largely digitised and increasingly integrated around BIM, for a complete digitalisation of construction industry, structured information models would need to be available on construction site where the information is used to shape material world. However, on the construction site the IT infrastructure is not readily available. Things began to change with the introduction of mobile computing [10]. The field is still evolving.

1.1. Motivation

The outputs of construction information processes (designs, plans and schedules) provide the control information for the material processes in construction [42]. The media to bring the information from the digital models to construction site where it is used to shape physical reality are still 2D documents such as floor plans, cross sections, sketches, etc. The construction site is integrated into the construction process using media and formats that pre-date computers. Situating information and establishing the relation between the real world of the construction site and design information remains the task of humans. In this task they are not assisted much by technology. Relevant information from the model has to be extracted, based on the user's role in the project, location and time. The graphical representation of this information in 2D must be situated and contextualised with the physical 3D reality for which people rely on their spatial awareness. It is the technologically largely unassisted human mind that is bridging the gap between the real world of the construction site and the virtual world of the information model and is integrating the two. This is what engineers on site have been doing since the introduction of drawn design information centuries ago. The problem at hand is how to assist this process with technology.

The hypothesis of our research of augmented reality (AR) was that by using a synthetic environment that enables the integration of 4D building information models into the live picture of real world it is possible to improve the understanding and ease the use of project information. It should be possible to measure this improvement.

We claim that such synthetic environment is augmented reality. It is not just feasible, but it is also more effective than the more traditional, well-established presentations on blueprints or on-screen projections.

* Corresponding author. Tel.: +386 1 4768 606.
E-mail address: mdolenc@itc.fgg.uni-lj.si (M. Dolenc).

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The specific questions the paper asks are (a) does AR have potential in structural engineering, (b) how big an improvement this technology is and (c) what are the barriers to its adoption. To answer these questions we had to develop a methodology, which is generic in nature and applicable to other technology related research in the interdisciplinary area of structural engineering and computer science.

1.2. On research methodology

A lot of research in engineering in general and in construction informatics in particular does not analyse existing phenomena, as is the case in natural sciences. Rather, it synthesises (creates) new solutions and improves technologies. Establishing success or failure of this kind of research is methodologically difficult for at least two reasons.

First, whatever the technology is doing to assist in the construction process has already been done without that technology for decades or centuries. So naturally it can be done with some additional help of new technology as well. It hardly can fail. In Karl Popper's terms [17] the refutability of such research is questionable.

Second, researchers can create prototypes that prove an idea but do not have the resources to create commercial grade software. Research prototypes lack robustness, friendliness and usability of commercial systems created by hundreds or perhaps thousands of programmers. Measuring the success of crude research prototypes does not do justice to the potential of the technology.

In our research this problem was addressed by an innovative combination of several evaluation methods, both theoretical as well as empirical. Theoretical foundations are set on phenomenology. It provides philosophical basis for the hypothesis that augmented reality has a potential. A prototype was built. It was tested and studied in real life settings to assess the current technological capabilities and limitations. Finally the usefulness of the developed prototype was examined by conducting structured interviews with potential end-users.

1.3. Paper structure

In the introduction the research context, goals, method and the hypothesis were defined. Section 2 presents the related work. Section 3 continues with the description of the design and implementation of the prototype. Section 4 presents the theoretical self-evaluation of the developed prototype and the preliminary field tests. Those results were used as input data for the empirical part of the research – the survey – that is presented in Section 5. In the conclusions the results are analysed and the hypothesis is revisited.

2. Background and related work

In this section augmented reality is discussed from theoretical, technological and practical points of view. It explains our understanding of the building information modelling and its relation to construction project documentation. As construction can be understood as the materialisation – physical realisation of the project documentation [26,31,41], a philosophical discussion on relations among human mind, virtual and real environment is provided.

2.1. Augmented reality

Although virtual and real environments are two completely different entities it is practically impossible to make a clear boundary between them. They can be better presented with two poles of continuum [25], the real and the virtual. The virtual environment must be completely predefined since computers cannot make their own assumptions [16]. The real is a complex mixture of natural events and items that exist in one of the pole of the continuum. Reality, therefore, includes all that can be created, built, planned, observed, understood etc.

The other extreme of that continuum is a virtual environment, which allows engineers and designers to design objects in imagined, virtual, and designed, but not yet materialised world. Augmented reality is therefore the middle segment of continuum where virtual elements are added to real world [29].

Building information models are actually representations of designed reality, aimed at improving the perception of ideas and exchange information [41]. By advanced rendering of the models and surroundings, the user is offered a greater amount of information. This can reduce the possibility of misinterpretation of the designs [3]. With technological progress greater degree of realism can be achieved but according to this theory the perfect model cannot be established since reality presents a limit that can be approached but never reached [36]. Augmented reality on the other hand offers a different approach. It takes the live picture of real surroundings as a base to which virtual elements are added. With that in a given point in time and space the user's interpretation of proposed digital solutions can be easier [14].

There are many terms used to define the segment of continuum between the extremes of the real and the virtual: mixed reality, amplified reality, augmented reality, mediated reality, diminished reality, augmented virtuality, virtualised reality [22]. In this paper the term, augmented reality (AR) is used since our application augments the insight to the real situation for the user.

2.2. Building information modelling/model

By definition the building information modelling is a process of digital designing, which results in some form of a building information model (BIM). Ideally it should include all the data needed for the construction instead of the data being scattered throughout numerous drawings, folders, tables, reports, documents, etc. [9].

The basic premise of building information modelling is to enable frictionless collaboration of different actors (professions) at various stages of a building life cycle, integrated around a shared model. The actors may enter, retrieve, update or adopt the information in BIM and with that justify their roles as the participants in the construction process [6,24]. The 4D BIM is a model that includes the temporal properties. The 5th and 6th dimensions of BIM sometimes denote cost and facility management [32].

2.3. Project documentation

Formally speaking, the project documentation that is required by Slovenian legislation is defined by the Construction Act [40]. It should consist of the conceptual design, preliminary design, basic design, detailed design, and as-built design.

In this paper the term "project documentation" is used broader than formally defined by Slovenia legislation. The term project documentation is used to denote a set of all documents needed for the construction. It includes all information contained in building information models.

2.4. Intersection between conscious real and virtual

The role of augmented reality can theoretically be explained in the context of the meaning triangle in Fig. 1 [31]. The concept is an idea in the mind that refers to that specific referent (real world object). The symbol is a visual or audible signal symbolising the idea about that referent.

The presented example shows that it is possible to establish a direct relation between referent-reference and reference-symbol (Fig. 1). The first is called referencing and the second modelling. The relation between the symbol and the object is more complicated as both exist outside the mind of the human. However, one could say