



# Technological advancements in synchronous collaboration: The effect of 3D virtual worlds and tangible user interfaces on architectural design

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## ARTICLE INFO

### Article history:

Accepted 24 August 2010

Available online 24 December 2010

### Keywords:

Synchronous design collaboration

Remote design collaboration

Co-located design collaboration

3D virtual worlds

Tangible user interfaces

Design cognition

Protocol analysis

## ABSTRACT

This paper presents and evaluates two current advancements of collaborative technologies for architectural design. The paper focuses on technologies that support synchronous design collaboration, in particular, 3D virtual worlds for supporting remote design collaboration, and tangible user interfaces (TUIs) for enhancing co-located design collaboration. Both technologies enable designers to collaborate by interacting with 3D models as the design representations. The paper analyzes the effect of these technologies on design collaboration and cognition through a comprehensive interpretation of the results from two independent studies. These two studies, using protocol analysis and each focusing on a different mode of design collaboration, provide the foundation for characterizing the designers' cognition, communication and interaction when using the new technologies. The 3D virtual worlds study investigates remote design collaboration in a 3D virtual world in order to understand the changes of design behavior when designers are physically remote but virtually co-located as avatars within their design representation in the form of a 3D model. The TUI study measures the effect of a tabletop system that integrates TUIs together with augmented reality (AR) on designers' cognitive activities and design process in co-located design collaboration. Finally, the analysis and comparison of the results converge in a set of recommendations for the future development of collaborative design technologies.

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## 1. Introduction

Design has often been described as a reflective practice that refers to a learning and exploration process where iteration is the interesting part [1]. While designers can conduct such reflective practice on their own, the complexity of the design projects and the influence of global economy have made such cases very rare. In practice, designs collaborate with other designers within the discipline as well as other experts across the discipline. Lahti et al. [2] define design collaboration as a process where designers dynamically communicate and work together, aiming to collectively establish design goals, search through design problem spaces, determine design constraints, and construct a design solution. While individual designers contribute to the design development, collaboration implies teamwork, negotiation, and shared representations.

Collaborative technologies support design in several ways. This paper focuses on technologies that support synchronous design collaboration. The particular technologies we consider are 3D virtual worlds for supporting remote design collaboration where design

activities can occur at the same time with the participants remotely located, and tangible user interfaces (TUIs) for enhancing co-located design collaboration by augmenting the perception of the shared design drawings or models through tangible interactions with the digital design representations. Both technologies enable designers to collaborate by interacting with 3D models as the design representations. This paper discusses and evaluates the effect of these two technologies on synchronous design collaboration in relation to the changes of designers' cognition, communication and interaction when using the new technologies.

The studies concern the conceptual development of architectural design where the design solution is represented as a 3D digital model that evolves as the record and the focus of the design process. Bringing designers into virtual environments has the potential to improve their understanding of the design representations during the collaboration. 3D virtual worlds and TUIs are two very different approaches to making the design model accessible to remote and co-located designers. Numerous 3D virtual worlds and TUI applications have been developed for the Architecture, Engineering and Construction (AEC) domain. However most of them are lab-based prototypes and there is a general lack of empirical evidence available for understanding and evaluating their effect. This paper utilizes the results of two cognitive studies as the basis for characterizing the designers' cognition, communication and

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