TANGIBLE AUGMENTED REALITY FOR DESIGN LEARNING: AN IMPLEMENTATION FRAMEWORK

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Abstract. Nowadays, it is becoming more and more popular for teaching and learning to be supported in technology-supported settings. These digital technologies create new instructional methods. Tangible Augmented Reality (AR) technology can construct an innovative and interactive learning space by merging computer-generated learning materials and stimuli of virtuality into a real space. Different cognitive and social-learning processes might be involved with different learning activities that can be potentially supported by different technology modes of tangible AR. This paper discusses an empirical research framework for designing and implementing tangible AR technologies to improve the pedagogical effectiveness of learning processes involved in architectural design education. The research framework includes the theoretical process of applying tangible AR in design learning, the devised experimentations and associated methodology. Issues and benefits of incorporating tangible AR into architectural design learning are also investigated and discussed.

Keywords: Augmented Reality, architectural design learning, framework, learning theory, tangible interface.

1. Introduction

Learning in technology-rich settings is becoming general practice (Kaufmann, Schmalstieg and Wagner, 2000). A variety of computer technologies such as e-learning and virtual learning environments have been used to improve learning in design activities (Doswell and Blake, 2006). More and more instructional methods can be realized in on-line tools and mobile devices, and new media method combinations emerge with their own specific affordances. Current instructional methods seem to be not sufficient to educate quality architecture designers.

It is envisaged that a combination of real and virtual media will open new perspectives in teaching and learning and low-cost Augmented Reality (AR) solutions can be developed to support different learning activities. Tangible AR technology can seamlessly merge computer-generated learning materials and stimuli into a physical learning space. AR learning and training systems have been developed in the area of military combat (Department of Defence 2002b), training in industrial maintenance (Schwald and de Laval 2003), and school education (Kaufmann, Schmalstieg and Wagner, 2000). The promise of effectiveness is supported by evidence from mental health research, which reveals that a virtual experience can evoke the same reactions and emotions as a real experience (Schuemie, var der Straaten, Krijn, van der Mast, 2001). Theoretical work on the use of tangible AR interfaces in design learning environments has been slowly materialized. This paper develops a theoretical framework for conceptualizing the potentials, prospects and latent trends of tangible AR for improving the pedagogical effectiveness of experiential and collaborative learning processes in architectural design education. Moreover, it will be followed by prototyping several tangible AR systems for experimentation of theoretical work, and the developed prototypes will be used as test beds to exam some aspects of the theoretical framework.

Furthermore, the importance of this research is more emphasized on developing a comprehensive theoretical process of integrating tangible AR into current stream of design learning. What distinguishes this work with others is a focus on theoretical framework for guiding the design of tangible AR systems instead of merely on system development. Although tangible AR interfaces have become popular in the computing society in last decade, most research work is merely and predominantly focused on technical interface development with few theoretical and empirical efforts in its use for design learning. Therefore, there is a need to build a systematic research framework to guide optimized design and implementation of tangible AR systems. The practical contribution of the presented work is that certain tangible AR prototypes that will be developed based on this framework will be integrated as a supplementary teaching aid into some of the units of study in architectural and urban design curriculum. The research focuses on the architectural and urban design learning realm. The challenge in urban design education, as in many design-orientated subjects, is to articulate written learning outcomes and complementary assessment criteria which have to incorporate these important cognitive attributes such as creativity, imagination, originality, and spatial thinking. Tangible AR system can create strong spatiality to learners based on directness of the physical effect.

2. Theoretical Framework

This research framework aims to establish the scientific principles and produce methodological guidelines for creating usable tangible AR technologies by integrating knowledge from various fields that address the human factors (perceptual, cognitive, and characteristics of real and virtual learning in design discipline), information visualization, information technology (hardware, software, communications), human-machine interaction, and construction methods. Figure 1 presents four knowledge domains which should be integrated to address the research issue. From this integration, a theoretical process is proposed as depicted in Figure 2.

The proposed research will also focus on supporting learning practice based on experiential and collaborative learning theories. Tangible AR learning space offers a richer form of experiential learning not available previously. Dewey's experimental learning model (Dewey, 1938), which emphasizes the generation and testing of hypothetical problem solutions, can be supported by AR that facilitates simulation and "what-if" analyses. In Augmented Reality, there is an intimate relationship between virtual and physical objects. Tangible AR-based learning environments can present objects with natural affordances for supporting interactions. Tangible AR can enable students to acquire concrete learning experiences through active experimentation. Students can actually 'experience' theory in a more familiar form, since the practical experiment enables the students to "observe and reflect on" the results of learning tasks and assignments.

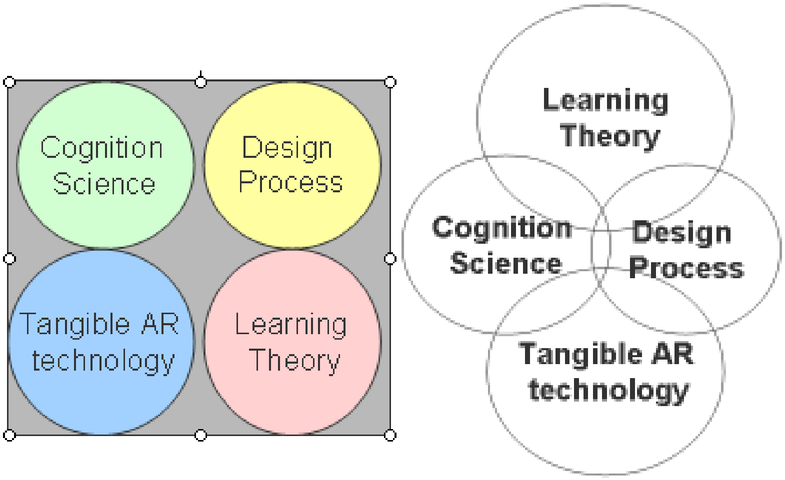

Figure 1. Interdisciplinary research.

Figure 2 represents the interdisciplinary efforts across the four different knowledge domains. Tangible interfaces can provide tactile sensational feedback and Augmented Reality visual interface can enhance human's perception of digitalized feedback from such interaction. This combination directly provides concrete experience. Learners receive the stimulus through the processing continuum which contains the broad diversity of learning styles ranging from constructive to analytical learning. Kolb's four-stage learning cycle (Kolb, 1984) is mapped onto the sequence of the processing continuum. Meanwhile, the typical design process has been featured as a spiral process to model how the various design elements fit together (Zeisel 2006). The initial mental image/model is perceived and constructed visually from reflective observation and tactilely from tangible feedback. For each cycle along the spiral design process, designers proceed through by presenting, testing, and re-imaging responses to a set of related problems. Abstract concepts are then reinforced by this continuous combined feedback from visual and tactile channels. Designers then converge the current abstract concept to the active experimentation. Following the above immediate action, they return to problems that have already been studied to revisit earlier decisions throughout this design activity. The output is the knowledge gained from the expressive, playful, reflective, situated and interactive learning activities from tangible AR systems.

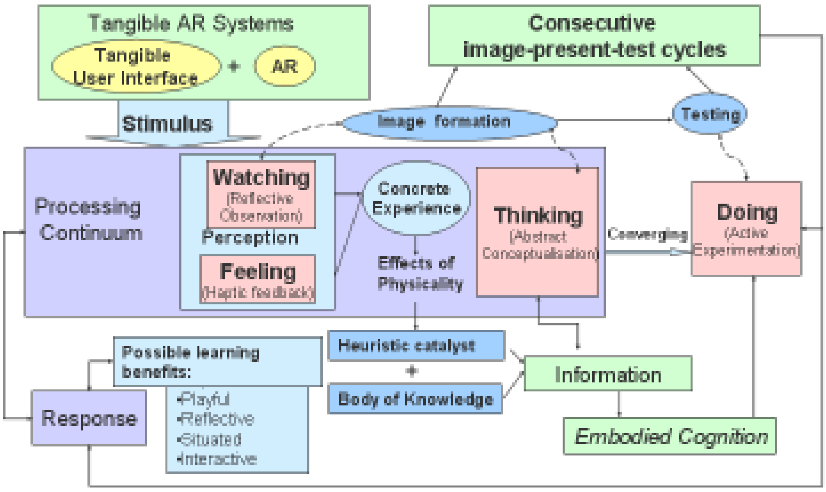

Figure 2. Theoretical process for applying tangible AR concept and technology into architectural design learning

Current architectural design education involves the critical need to integrate theoretical and practical learning sequences. There are proven benefits from interleaving theoretical and practical learning (Attwell and Brown 2000), and there is a growing need for innovative teaching and learning concepts and technologies which can support such integration. The purpose of this research is to explore potentials for students to become more empowered with tangible AR interactions.

The embodiment from cognitive science suggests that there are some stronger linkers between physical activity and cognition (Barsalou, 2005). Tangible AR systems are envisaged offer more opportunities for learners to increase the physical activities which have shown to influence and constrain cognitive process (Barsalou and Niedenthal 2003). While learners watching visual representations from AR systems combined with direct feeling through physical materials from tangible interfaces, perceptual and motor responses are then complemented to have a more accurate assessment of the current learning outcome which in turn highly inter-links the perceptual and cognitive processes involved. Materializing knowledge into physical forms can help learners to further advance the understanding of those purely gained from written media.

This theoretical process provides potentially beneficial categorizations of design learning activities with tangible AR interfaces. High integration of representations from visual and haptic stimulus is unique feature of tangible AR systems which exposes learners to multi-channels from the concreteness and sensory directness**.** For example, a common discussion context consisting of same set of physical objects and public screen can then be created to physically bind everyone for more effective communication and discussion. Everyone has equal access to the tangible AR interface. They can easily do comparative work with concurrent interaction which leads to effectiveness of collaborative learning activities compared to the typical desktop setup with mouse and keyboard.

3. Research Methodologies of Validating the Framework

There are types of experimentation planned: one for individual experiential learning and one for social learning. Criteria for experimental design can include suitability for the experimental task, self-descriptiveness, controllability, conformity with user, expectations, error tolerance, and suitability for learning (Kaufmann, Steinb gl, D nser, and Gl ck, 2005).

3.1. EXPERIMENTATION ON EXPERIENTIAL LEARNING

The experimentation stage will validate the effectiveness from the experiential learning based on level two of Kirkpatrick's teaching and learning evaluation classification (Kiyokawa and Billinghurst, 2002). This level assesses the amount of learning that has occurred due to the integration of the tangible AR learning space. Basically the experimentation will compare the learning results with and without the experience in the tangible AR learning space. Classroom teaching will be a possible method to be used as the comparison benchmark to measure the extent to which students can make progress in skills, knowledge or attitude with tangible AR learning tools.

3.2. EXPERIMENTATION ON SOCIAL LEARNING

Students work better together if they are focused on a common workspace instead of working on separate computers, even if they are side by side. When students work at a table, the space between them is used for sharing communication cues such as gaze, gesture, and nonverbal behaviors (shared communication cues). This results in conversational behaviour that is more similar to natural face-to-face collaboration than to screen-based collaboration (Kiyokawa and Billinghurst, 2002). According to the theory of social constructivism, collaborative activities improve the learning effectiveness (Burr, 1995). In the tangible AR learning scenario, students are involved in collaborative learning tasks in a face-to-face manner. The research will compare the tangible AR systems with traditional collocated design methods and settings.

The approach of protocol analysis will be used to analyze the social learning outcomes and effectiveness from the use of tangible AR tool. Design thinking can be induced from the behaviours captured from the oral communication, including verbalizations, drawing and gestures. In particular**,** the links between physical actions and digital effects will be analyzed through how the learners manipulate or interact with tangible AR systems. For example, in the learning activity of measuring the distance between physical mock-up objects, it can be recorded that how fast and accurate the learner can reflect from the physical objects and how this innovative media helps learners to construct expressive representations passively.

The experimentation will base the evaluation on level one (reactions) of Kirkpatrick's teaching and learning evaluation classification (Kirkpatrick, 1998). Evaluation at this level measures the opinions from students on the tangible AR learning space, which is also called face validity. Special questionnaires and associated data collection strategies would be developed in order to assess the collaborative learning effectiveness of the tangible AR learning space. The research will base the development of the questionnaires on the pilot study and widely accepted theoretical learning models, such as Burr (1995) that can be easily generalized to the tangible AR case.

Both experimentations will use Interdisciplinary Evaluation of Learning Tools (CIELT) as shown in Table 1 adapted from Kaufmann (2004). For example, from the pedagogical perspective, the assessment can be gained through the Pedagogical Meaningful Learning Questionnaire (PMLQ) (Nokelainen, 2006). There are different usability sub-dimensions under the PMLQ. Six sub-dimensions have been identified as learner control, learner activity and cooperative learning, goal orientation, applicability and added value. Added value can be assessed based on overall added value for learning, effectiveness for learning, added value from physical interactions.

TABLE 1: Adapted from the overview of the different levels focused by CIELT (Kaufmann, 2004)

Levels focused	Framework	Methods
Learning outcome	Pedagogical aspect, Cognitive aspect	Comments from experts
Learning process	Cognitive aspect	Observation, Expert ratings, informal questionnaire
User acceptance	Orientation aspect +effective parameter	Questionnaire
Usability	Technical aspect	Questionnaire
Technical requirements	Technical aspect	Observation, Questionnaire

4. Educational Benefits

The preliminary work presented in this paper is an initial effort towards the application of tangible AR in education and the implementation of results can become a basis for tangible AR in broader learning activities in education. The proposed work can be used as a reference for future researchers and educators who are interested in picking up this technology for their own architecture educational purposes. The knowledge and technology created from this work can be generalized and transferred across other related design educational areas that prefers to physical engagement into the learned domain knowledge. The areas that can potentially benefit from this frontier technology include engineering design, industrial design, product design, etc.

The practical contribution of the research is to explore potentials for students to become more empowered with tangible AR-based learning. Tangible AR-based learning can also make architecture educators and researchers reconsider how students can learn better. The benefits for educators to become involved in the development of learning content associated with tangible AR systems are also substantial. This may be further encouraged using participatory development methodologies to ensure that instructors, tutors and students have a greater say in dedicated content developed for tangible AR-based learning, and importantly to ensure compliance with sound pedagogic design principles as well as alignment with learning outcomes and assessment.

5. Summary and future work

This paper develops a research framework for conceptualizing the potentials, prospects and trends of tangible Augmented Reality as a digital instructional method for improving the pedagogical effectiveness of experiential and collaborative learning processes in architectural design education. Different cognitive and social-learning processes involved in different learning activities are also considered into the presented theoretical process that can be used to design and implement tangible AR technologies for different educational needs. The devised experimentations and associated methodology are also discussed. Future work will be prototyping and experimenting several tangible AR systems based on the theoretical process to facilitate the extent of knowledge/skill transfer for certain architectural design learning activities. The comparison work will also be conducted to measure the different outcomes between using the tangible AR systems and the other representations. For instance, some experiments can be planed to make the contrast with the existing approaches such as the hand sketches and the wood blocks.

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