

VIRTUAL REALITY FOR MEETING INTERACTION IN INFRASTRUCTURE CONSTRUCTION PROJECTS

Janne Porkka & Timo Kuula

VTT Technical Research Centre of Finland, Finland

Kalle Kähkönen & Jukka Rannisto

Tampere University of Technology, Finland

ABSTRACT: *Urban planning and infrastructure projects of varied sizes are increasingly utilizing model-based applications at planning phase. Although the use of virtual models has its advantages, there are multiple challenges that diminish their potential in project use. These challenges are related to either non-human or human topics. The non-human topics cover issues like deficient processes, practices and tools. The human-related topics include for example lack of communication and interaction between relevant stakeholders. The interaction is a key element in current design practice due to the high number of disciplines involved in design formation and decision-making.*

During the past years, many key stakeholders have experienced difficulties in changing the current way of working with model-based practices. Virtual reality (VR) has been found to offer promise for design visualisation to convey messages with reduced communication difficulties between stakeholders. This paper draws findings from observations in one meeting at an on-going large infrastructure construction project in Finland. In this case study, virtual reality has been used in project management meetings to facilitate communication and to support decision-making. We consider how the use of virtual reality actually influenced on group dynamics and make concluding remarks underpinning the use in a traditional meeting room environment.

We have used activity theory as a framework to begin method development for observing and analysing the effects of virtual reality on interaction and related work practices. The empirical findings point out, that new visualization instruments have effects on the 'division of labour'. Following five traditional meeting interaction characteristics showed changes at group dynamics. When virtual reality was used as a presentation tool, the interaction between participants became more balanced. Activation of all participants, most probably, leads to enhanced mutual understanding, and furthermore to better results in the whole project.

KEYWORDS: *Infrastructure construction, Virtual Reality, Meeting, Interaction, Decision making*

1. INTRODUCTION

Communication in large urban planning and infrastructure projects usually involve a great number of stakeholders, which is a special challenge. It can mean different things to dissimilar people in different situations, and may also have a variety of different meanings, contexts, forms and impacts (Dainty et al., 2006, p22). Major development projects usually take a long time to proceed, even up to 25 years or more (Porkka et al. 2012A). Many important decisions are made early, such as boundaries for upcoming costs, functionality, usability and relation to surroundings. Time is short to discuss in these subjects in early meetings. There are many stakeholders, who view the process from different perspectives, including professionals such as engineers, architects, and planners and non-specialists such as clients and users (Bouchlaghem, 2005). Communication capabilities of knowledgeable participants may also be intensified, when compared to stakeholders with narrow understanding. Sometimes there is also confusion with technical language and adversarial culture where companies value their interest, preventing straightforward information flow between stakeholders (Dainty et al., 2006, pg.2).

Transparent communication is a necessity for active stakeholder contribution. Many of the problems that develop in projects are a result of both the temporary and interdisciplinary nature of project teams (Dainty et al., 2006, pg.2). Hence, the choice of which tool is the most appropriate, depends upon, the nature of the information and recipient, and the desired outcome from the communication. (Dainty et al., 2006, pg.83). A traditional design communication is often built on a paper-based graphical representation, which consumes time and moderates

Citation: Porkka, J., Kähkönen, K., Kuula, T., & Rannisto, J. (2013). Virtual reality for meeting interaction in infrastructure construction projects. In: N. Dawood and M. Kassem (Eds.), Proceedings of the 13th International Conference on Construction Applications of Virtual Reality, 30-31 October 2013, London, UK.

teamwork (Porkka, 2012B). Currently model-based applications are being increasingly utilized at planning phase. Virtual reality (VR) offers a promise for design visualisation to convey messages without communication difficulties (Reich et al., 1996). From a variety of tools available for communication, visualisation is the easiest common language, where professionals and non-specialists are able to relate and understand the content of design proposals (Porkka et al., 2012B).

The benefits of visualisation in group context have not been thoroughly addressed. Use cases have illustrated the benefits of synchronous collaborative information visualisation, but very few empirical studies have rigorously examined the impact of visualization on group knowledge work (Bresciani and Eppler, 2009). Bresciani and Eppler (2009) reported visualization helping to achieve higher productivity, higher quality of outcome and greater knowledge gains. Moreover, visualization also helps to work more collaboratively and communicate ideas efficiently (Bouchlaghem et al., 2005).

Success during project execution depends increasingly on individual capabilities to work together. Challenges are often related to the unique and complex nature of projects. Visualization techniques can facilitate shared understanding across interdisciplinary groups, which is required between all of the parties involved in collaborative design methodologies (Bouchlaghem, 2005). Moreover, virtual reality has started to be included to participatory methodology (Mobach, 2008). Although the use of virtual models has its advantages, there are still multiple challenges that diminish their potential in project use. These challenges are at high level related to non-human or human topics. The non-human topics cover issues like deficient processes, practices and tools. The human-related topics include for example lack of communication and interaction between relevant stakeholders. Currently most virtual reality applications, for example, require manual work to generate virtual models. There is need for cost-efficient applications, connecting intelligently to planning process and modelled plans. If the virtual model is generated nearly automatically, virtual reality applications become very stimulating for everyday use. Interaction is a key element in current design practice due to the high number of disciplines involved in design formation and decision-making.

This paper focuses on the observations made in one particular project meeting partially utilising virtual reality in communication in an ongoing large infrastructure construction project in Finland. First, we set out the key theoretical principles for virtual reality applications and describe the methodological approach of activity theory used in observing the meeting interaction. Virtual reality was used to facilitate communication and to support decision-making. Later, we consider how the use of virtual reality actually influenced on group dynamics and make concluding remarks underpinning the use in a traditional meeting room environment.

2. INTERACTION IN MEETING AND ACTIVITY THEORY

Construction industry is highly knowledge and people intensive. The interaction tends to be characterised by unfamiliar groups of people coming together for short periods before disbanding to work on other endeavours (Dainty et al., 2006, page 22). It's complicated to combine individual project team members' diverse skills, expertise and knowledge efficiently in meetings. Therefore, work practices in design formation are shifting towards more cooperative approach. Collaborative and participatory design methodologies are more and more highlighted. The collaborative aims at improving cooperation between professionals, while the participatory methodology contributes to citizens and end-users. Nevertheless, the teams operate through a set of varied meetings in construction industry. Main types of typical project meetings can be classified as:

- i) Industry professionals' meetings, i.e. master plan review meeting by the core design team.
- ii) Non-expert meetings, i.e. public hearing events.

In this paper, we focus on interaction between industry professionals. Unfortunately, there is not just one way for researcher to collect and analyse conversational data from this kind of meetings. Researchers tend to make their own conceptual categories for conversational data. We decided to look for a generic framework, which enables us to analyse interactions in meaningful perspectives.

One potential theory in social sciences to investigate collective activity and interaction is activity theory. The roots of activity theory have its origin from Russian psychology, and in Scandinavia the attention has evolved from individuals towards community. The theory relies on the concept of expansive learning, where the learners construct a *new object* for their collective activity and implement this *new object* in practice (Engeström, 2010). We have utilised the activity system model as a theoretical framework for analysing the meetings. We examine a

micro level concentration through individuals participating in the meetings and reflect perceived results back to whole project interaction at macro level.

The activity theory model is a general description of collective human activity with seven key elements linked together (Engeström, 1999). In the activity system model (University of Helsinki, 2012), the *subject* refers to an individual or a sub-group whose agency is chosen as the point of view in the analysis. The *object* refers to the 'problem space' at which the activity is directed and which is moulded and transformed into *outcomes* with the help of physical and symbolic, external and internal mediating *instruments*, including both tools and signs. The *community* comprises multiple individuals and/or sub-groups who share the same general object and who construct themselves as distinct from other communities. The *division of labour* refers to both the horizontal division of tasks between the members of the community and to the vertical division of power and status. Finally the *rules* refer to the explicit and implicit regulations, norms and conventions that constrain actions and interactions within the activity system.

Since the elements of activity are linked together, changes in one element affect the others. The changes may also cause contradictions between the elements. For example, what would happen when virtual reality as an 'instrument' is added into the system? In this paper, one particular meeting is seen as a case for observation and analysis. Thus, the meeting represents a "micro activity system" with participants as 'subjects' and meeting goals as 'objects'. However, the activity system perspective also reveals the more complex nature of the construction project and how meetings are bounded to the larger picture.

3. CASE STUDY

This paper builds on a case study, one meeting in a large infrastructure construction project in Finland, where virtual reality was used concurrently to traditional presentation methods in facilitating communication and to support decision-making. The client of the project is a governmental organization, who ordered the planning work from consultants and appointed experienced professionals to follow up the planning work. The team has prepared a general plan and is currently in process of developing a detailed plan. The detailed plan determines the accurate positions, identifies land allocations, and specifies traffic arrangements also to pedestrians and public transportation (The Finnish Transport Agency, 2010). However, this research aims at developing a method to observe meeting interaction and facilitates the developed method in one particular meeting situation. Once the method is tested and developed, the approach may become an integral part of procedural changes in organising project meetings.

3.1 Subject of Research

The subject of research was a regular project management meeting during the detailed plan preparation phase. The meeting was held between the client, appointed professionals and consultants, encompassing seven participants from which six were men and one was woman. The ages of seven participants varied between mid thirties to mid fifties. The management team was experienced and four out of seven members had lots of practical knowledge from similar projects. The rest were also skilled in their assigned tasks. This set up created an uncomplicated atmosphere for the project management meeting. The stakeholders appreciated each other, and communication was transparent and straightforward throughout the whole meeting.

The schedule of meeting was remarkably tight and agenda included plenty of topics. Since the project is large, the disciplines are progressing differently in various parts of the plan. The aim of the meeting was to share understanding and discuss issues that need instant attention. Altogether, the whole meeting lasted for four and half hours. In the beginning, the team browsed through the economical issues, and later, the research on observing interaction in actual planning topics started. The research consisted from seven topics. The three-hour section was held without breaks. The plan was developing and in one topic they had just started to collect ideas, while some others already had a preliminary plan.

The meeting was organised in a standard meeting room, which is presented in Figure 1 (Fig 1). Participants were seated on two-sides of a long table, and the whiteboard to project images was at the end of table. The consultant representatives led the meeting. Their two managers first introduced the topics. After the introduction a discussion period started and all participants had an opportunity to share their opinions. Consultants also had a project secretary, who showed the materials from beamer and distributed printed materials to stakeholders. The secretary wrote official meeting notes and operated various tools for modelling and virtual reality applications.



Fig. 1: Meeting room setup and two tools used in making decisions - a traditional map on the left and a virtual reality presentation at right (Photos courtesy of Janne Porkka).

Conversations in the meeting were observed by a group of four researchers. Before observing the interaction, researchers assumed that the use of virtual reality has positive influences on collaboration and further to assisting the decision-making. To complement observations, the whole meeting was recorded with sound and several photos were taken for documentation. The researchers took field notes and had an access to official project bank for shared materials and documents.

3.2 Applied Virtual Reality Application

Many key stakeholders have experienced difficulties in changing the current way of working towards model-based practices. Virtual reality has been found to offer promise for design visualisation to convey messages with reduced communication difficulties between different stakeholders. In other words, virtual reality lowers a threshold to interact. Unfortunately, virtual reality models usually require manual work upon creation from modelled plans. Since the plans are composed of numerous sub models, the effort of manual work done repeatedly might be too cumbersome for everyday production. There is a need for cost-efficient off-the-shelf applications connected directly to these plans. Then, virtual reality applications become more usable for municipalities and developers.

Vianova's Novapoint Virtual Map (Vianova, 2013) has been applied in the case study. Multi-disciplinary and complex design data in standard data exchange format is semi-automatically converted with parametric rules into a virtual reality presentation. Multiple sub models are converted into the same presentation, and dynamic linkage keeps track on updates to combined model. User has many options for viewing data and design alternatives can be selected by managing layer visibility. Presentation reveals conflicts like two objects colliding, one object hiding another and faults in geometries. However, these are model-based issues that can be easily corrected.

The application has useful functions for meeting context. There are multiple navigation modes like driving and flying. For meetings the easiest navigation mode is pre-stored camera viewpoint and path. The conflicts can be stored as viewpoints with a comment, and request for change goes back to planners. Activities in Virtual Map may be recorded to images and video. The sharing of model is enabled to separate free viewer or web page.

4. RESULTS AND OBSERVATIONS FROM THE MEETING

This research aims at developing a method to observe interaction in a meeting context. The participants studied in project management meeting were consultants, experts and client, who altogether established the community interacting on objects. The studied objects were seven topics in the meeting agenda (see details in a Table 1). The division of labour included first the introduction of a topic by a consultant and then the object was open for discussion between participants. Therefore, each participant had an opportunity to pose comments, and in fact, these comments led to valuable considerations while all stakeholders interacted. When the discussion of topic reached an end, the consultants together with the client made the closing remarks on how the plan is developed further.

As presented in table 1, topics were presented with the help of various tools. The first and second topic included status and schedule presented by tables, text documents and bar charts. Both of these topics did not gain added value from leveraging virtual reality in communication. However, the discussion with participants revealed that

the added value comes when plans are accurate. Virtual reality was used in topics three and seven for design review and alternative comparison facilitated by maps, general plan, virtual reality visualization, alternative virtual reality visualization and section plans. Remaining three topics, numbered as four, five and six, were communicated with conventional tools like maps, text document, table, images and section plans in order to review designs. The partial use of virtual reality in communication enabled researchers to compare and contrast their impacts to conventional tools.

Table 1: General data and perceived results of observing seven topics in the project management meeting.

	Goal of topic	Tools used	Perceived communication (%)		Perceived comments (%)		
			Introduction	Discussion	Consultants	Client	Experts
Topic 1	<i>Status</i>	<i>Table, text documents</i>	83	17	38	25	38
Topic 2	<i>Schedule</i>	<i>Bar chart</i>	43	57	50	42	8
Topic 3	<i>Design review</i>	<i>Maps, General plan VR visualization</i>	17	83	47	31	22
Topic 4	<i>Design review, Idea generation</i>	<i>Maps, text documents</i>	56	44	50	25	25
Topic 5	<i>Design review</i>	<i>Maps, table, images</i>	48	52	57	24	19
Topic 6	<i>Design review</i>	<i>Table, section plans</i>	81	19	67	25	8
Topic 7	<i>Alternative comparison</i>	<i>Alternative plan VR visualization, section plans</i>	29	71	40	27	33

We observed how much time was spent on to communicate each topic and noticed significant time differences in communication. The perceived time difference, as presented in Figure 2, fluctuated from ten minutes to nearly an hour. The more the time was, the wider the topic appeared to be in terms of details or planned content. Within each topic, the dialogue was verified from video and researchers split the conversation into consultant’s introduction and discussion section. As an average, the percentage for introduction was 46% while discussions took 54% of the time. Interestingly, the share of introduction was significantly smaller in topics that utilised virtual reality, respectively 17% and 29% in tasks three and seven. On the other hand, the tasks with conventional tools seem to consume more time to be explained, as presented in Table 1 and Figure 3.

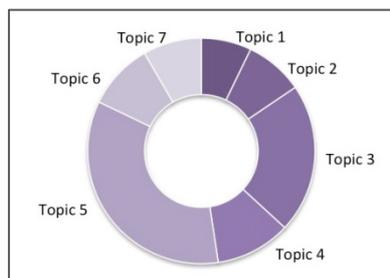


Fig. 2: Perceived length of seven topics in agenda as percentages from the whole meeting.

All representatives participated to conversations. Clients’ project manager was very experienced and interested to discuss, which led to an active role throughout the project management meeting. Within the discussions, the client had a strong linkage to appointed experienced professionals. Two of the experts were experienced with model based planning, and in fact, one of the aims in the whole project is to utilise model-based applications more efficiently in the planning process where virtual reality is applied to enhance communication.

The amount of comments participants made during communication is actually a reliable indicator for participation. The tracking emphasised how participants are participating. Moreover, instead of calculating every comment we focused on how many first comments the participants made to bring up a new subject to discuss

(see participants comments on right-hand side in Fig 3). When consultant started topic introduction we added one comment. When the introduction ended and participants started to bring new subjects to discussion, the calculation continued. For example, when someone posed a question: “what is the distance between the columns?” the resulting conversation was marked for the same participant because it provided the direction. Our approach promotes the activeness of participants. However, we want to remind that the results are based on the findings of one meeting. Thus, broader generalisations on how the use of virtual reality effect to interaction and meeting dynamics are preliminary. The sample of several meetings is needed to confirm the findings.

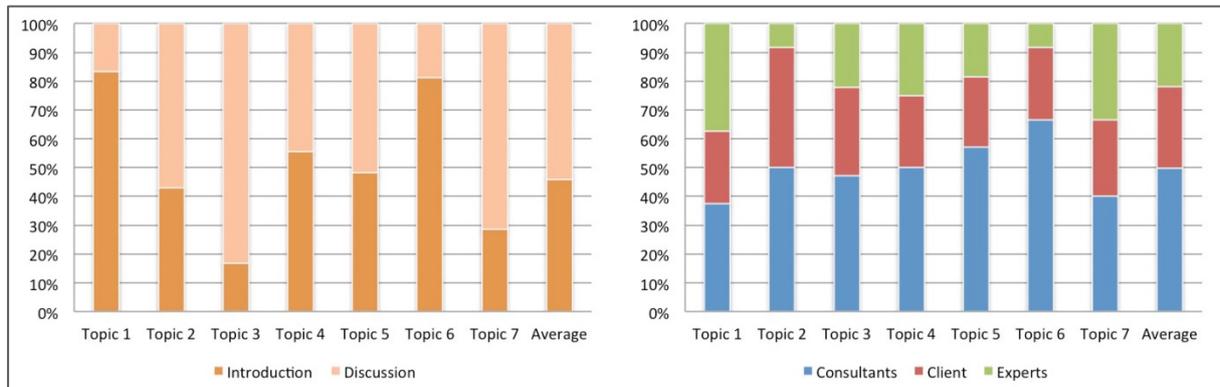


Fig. 3: Graphs from perceived communication times (left) and perceived participant comments (right).

Some participants, especially client and experts, appreciated the use of virtual reality in interaction. Throughout the conversations, participants often reflected plans to resident opinions and comments from regional businesses, to support detailed discussions. Virtual models in meeting were shown by the project secretary who did not contribute to other topics, and thus it appears that technology has an impact on the division of labour.

5. DISCUSSION

Project management meeting provides great perspective on how plan evolves constantly from meeting to meeting. The outcomes of this meeting are about to become objects for the following meeting. The use of model-based applications in early planning has been stated to provide coordination benefits (Porkka et al., 2012B). For this research a virtual reality solution enabling semi-automatic virtual model generation from modelled plans was used. The data from live meeting context gave us better understanding on the characteristics of virtual reality in interaction. Although the subject of research was not scientifically rigorous due to small sample, it clearly demonstrates how an active participation is essential for successfully reaching the meeting objectives.

Virtual applications have an additional value in introducing plan to participants. Compared to the traditional tools, such as text documents, tables and images, the introduction seemed to be quicker with the help of virtual reality. This is demonstrated in Figure 4, where it is obvious, that the content of the topic has a lot of effect on the discussion time. The goal of the topic four was to generate ideas. However, much time was spent to introduce the object. Altogether, it seemed that it was easier for participants to understand content more quickly when virtual model was used and more emphasis was paid on problem solving. Relations between discussions and introductions varied in a ratio from 0.2 to 5. When topic leveraged virtual reality the ratio was higher (2.5-5), meaning that there was over two times more discussion about the details of plan when compared to the traditional tools in introducing the plan. In other words, if there is certain time reserved to review a plan and introduction time is shorter, there is relatively more time to interact and discuss about the solutions for further development.

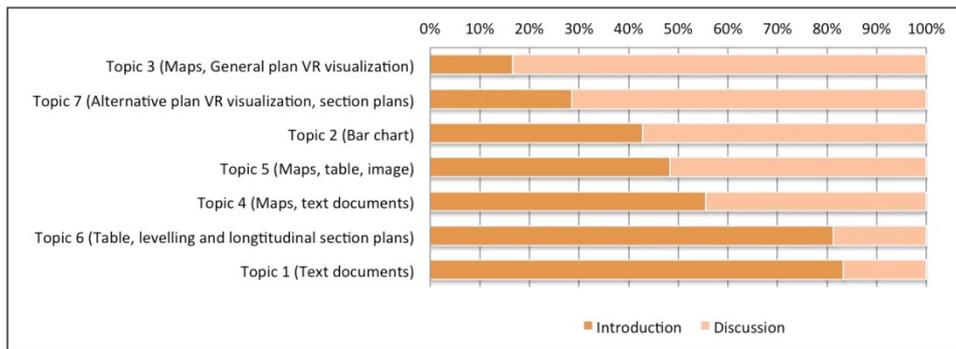


Fig. 4: Perceived topic communication (introduction and discussion) and tools.

We also noticed that virtual model helps to share understanding between the participants of various backgrounds. Thus, bringing virtual model as a new ‘instrument’ into the activity system seems to change the division of labour towards more democratic and even way to discuss. The degree of participation (see Fig. 5) reveals that consultants had a primary and leading role in the meeting. When virtual reality was used, the nature of the conversations changed and an increased participation of client and experts were noticed. As a resultant to that, the activity of consultants decreased. Therefore, it is also reasonable to consider that use of virtual models may shift the roles of participants towards activating more technically competitive younger generation.

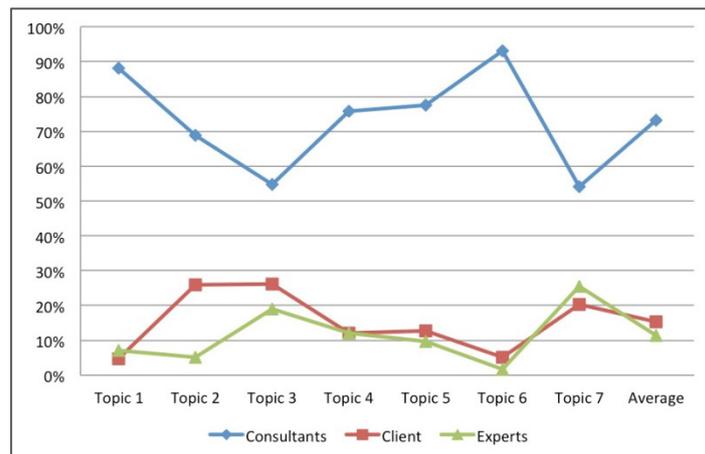


Fig. 5: Degree of participation during meeting (%).

6. CONCLUSION

This paper has presented observations from the project management meeting on understanding better, how virtual reality influences on meeting interaction. We have used the activity theory viewpoint as a framework to begin method development for observing and analysing the interaction and related work practices. In a nutshell, the developed method monitors following meeting characteristics: perceived communication time per topic, perceived communication time inside the topic (split to introduction and actual discussion), perceived amount of participant comments, perceived amount of first comments to bring new subject into the discussion, and degree of participation.

Active participation is essential for successfully reaching the meeting and project objectives as a whole. The empirical findings collected through observations and recordings indicate that bringing new technologies into a sensitive meeting situation must be facilitated carefully. Large projection-based immersive environments have potential to enhance collaboration and exchange of ideas (Simon and Scholz, 2005). Based on our findings from the traditional meeting room environment, new visualization instruments have effects on the ‘division of labour’ during the meeting. When virtual reality was used as a presentation tool, the interaction between participants became more balanced. This interesting group dynamics shift was supported by a remark that virtual applications

have additional value in introducing the plan to other stakeholders. There was over two times more detailed, beneficial discussion in comparison to using traditional communication tools. Balancing the degree of participation between participants, most probably, leads to enhanced mutual understanding, and furthermore to better results in the whole project. When there is a certain time reserved for plan review, virtual reality leads to better opportunities for developing the plan. Besides, it is also reasonable to consider that roles of generations are shifting towards the activation of younger people.

Efficient use of virtual reality requires procedural changes in organising project meetings. We recognised a contradiction between the 'subjects' and the 'rules'. Sometimes, the chairperson was unable to control time used in communicating one topic and allocated time for next topic diminished. Based on the activity theory, the more in balance without contradictions different activity system elements are, the better the interaction will be. However, it should be pointed out that activity theory alone is not sufficient for evaluating new meeting practices' impact on the whole construction project, thus supporting methods are needed. The impacts of decisions on design practices need more emphasis. The method presented and tested in this paper is a good starting point. People should be open to new ways of working and willing to take collaboration and participation methodologies into work practices. We will together, with case stakeholders, focus in the future for developing a new responsive design practice.

7. ACKNOWLEDGEMENTS

This research has been supported by the Finnish Funding Agency for Technology and Innovation (TEKES) under the project 'VIREsmart'. Authors are grateful for the team enthusiasts at Finnish Traffic Agency, Centre for Economic Development, Transport and the Environment, City of Espoo, Sito Ltd., Vianova Systems Finland Ltd., and Ramboll Finland Ltd. Main author of the paper, Mr. Janne Porkka, is a doctoral candidate in the Faculty of Built Environment at Tampere University of Technology. Special thanks for VTT colleagues, Mr. Juha Hyvärinen, Mrs. Mirrka Rekola, and Ms. Nusrat Jung, for support and constructive comments to develop content in paper.

8. REFERENCES

- Bouchlaghem, D., Shang, H., Whyte, J. And Ganah, A. (2005). Visualisation in architecture, engineering and construction (AEC), *Automation in construction*, Vol. 14, Iss. 3. pp. 287-295.
- Bresciani, S. And Eppler, M. (2009). Evidence from an experimental evaluation, *Visualization and Computer Graphics*, Vol. 15, Iss. 6. pp. 1073-80.
- Dainty, A., Moore, D. and Murray, M. (2006). *Communication in Construction, Theory and Practice*, Routledge.
- Engeström, Y. (1999). Innovative learning in work teams: analysing cycles of knowledge creation in practice, in: Engeström, Y. et al (Eds.) *Perspectives on Activity Theory*. Cambridge University Press, Cambridge. pp. 377-406.
- Engeström, Y. (2010). Activity Theory and Learning at Work, In Malloch, M. et all (Eds.) *The SAGE Handbook of Workplace Learning*, Sage publication Ltd. pp. 74-89.
- Mobach, M. P. (2008). Do virtual worlds create better real worlds? *Virtual Reality journal*, Vol. 12, Iss. 3, 163–79.
- Porkka, J., Jung, N., Jäväjä, P., Suwal, S., Savisalo, A., Päivänen, J. and Sireeni, J. (2012/B). Increased interaction with multi-user virtual reality in construction projects, in Lin Y-C. & Kan S-C. (eds.) *12th International Conference on Construction Application of Virtual Reality - ConVR 2012*. Taipei, Taiwan, November 1-2. pp. 434-42.
- Porkka, J., Jung, N., Päivänen, J., Jäväjä, P. and Suwal, S. (2012/A). Role of social media in the development of land use and building projects". In Gudnason G. & Scherer R. (eds.) "eWork and eBusiness in Architecture, Engineering and Construction, ECPPM 2012". Reykjavik, Island, Jul 25-27. pp.847-54.
- Reich, Y., Konda, S.L., Levy, S.N., Monarch, I.A. and Subrahmanian, E. (1996). Varieties and issues of participation and design, *Design Studies*, Vol. 17, No. 2, 165–180.

Simon, A., and Scholz, S. (2005). Multi-viewpoint images for multi-user interaction, *Proceedings of Virtual Reality'05*, IEEE, Germany, Bonn, March 12-16th, 7pg.

The Finnish Transport Agency (2010). *Road planning phases (In Finnish)*, electronic publication from The Finnish Traffic Agency and Centre for Economic Development, Transport and the Environment. 20 pg.

University of Helsinki (2013). Structure and description of activity system. Available online at: <http://www.helsinki.fi/cradle/activitysystem.htm> (Accessed 22.5.2013)

Vianova (2013). Novapoint Virtual Map product sheet. Available online at: <http://www.vianovasystems.com/Products/Novapoint-products/Novapoint-Virtual-Map#.UX2ZTpV21v0> (accessed 22.5.2013)