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Users' evaluation of a virtual reality architectural model compared with the experience of the completed building

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Abstract

It is important that the properties of a Virtual Reality (VR) model support its purpose in the specific context in which it is used. This study investigated how employees of a company experienced a VR model of their yet-to-be-built office building. We also compared the VR experience with the employees' experience of the completed building. The results showed that the employees felt that the VR model was a useful aid in the decision-making process concerning their future workplace. In addition, *The Semantic Environment Description Scale* was used to compare the experience of the VR model with the experience of the real building. The results suggest that the VR model gave a fairly accurate representation of the real building.

Keywords: Virtual Reality (VR); Usability; Architectural model; Realism; Experience

1. Introduction

The Virtual Reality (VR) technique, i.e. digital visualisation of 3D content in real time, has evolved from being a very expensive technique implemented on supercomputers handled by experts to a technique implemented on non-expensive PCs affordable even for small firms. However, the development of the technique has not been matched by research aimed at adapting the features of the VR technique to the different demands of the various situations in which it is used. The usability issue (taken in a broad sense) is thus of great importance in the context of VR. In the present study we investigate the usability of a VR model of a building and its environment at a late stage in the building process.

In general, research in Human Computer Interaction (HCI), including the concept of usability, has undergone a shift from being computer- and program-oriented to being more focused on the actual use context (e.g. [1,7,8]). However, as noted above, the concept of usability, although central in HCI research in general, has not been explored very much in the context of VR models. An exception is Kalawski [9], who developed general criteria and a general instrument for measuring the usability of VR models.

It is important that the properties of the VR presentation are adapted to the specific use context, e.g. the specific stage in the building process in which it is used, including the different categories of users using the VR model. For example, perfectly realistic lighting in a VR model would presumably be an excellent experience, but may not be worth the effort. Questions arise concerning how and why VR is used in the building production system.

Even today most of the design work in urban planning and architectural projects is done in 2D. The main tools used for communication between co-workers in the different

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phases are still 2D blueprints. Specialists then use the 2D drawings and sketches as references when creating the VR model. Cory [4] presented an analysis of the use of 2D, 3D or 4D CAD by Architectural, Engineering and Construction (AEC) companies in the documentation of the construction process. 4D adds time as a fourth dimension to the object's three geometry dimensions. Cory concluded that the use of 3D and 4D CAD could save money but that their full potential is not yet being utilised. Furthermore, Cory argued that industrial professionals need proof that the new tools are cost-effective. The same appears to be the case, although to an even greater extent, when VR is added to 3D and 4D. However, the use of VR in the building process is becoming more and more important and a great deal of research is currently being done to improve the VR presentation techniques. At the same time, the optimal way of using VR in the different stages of the building process is still not clear.

On a general level, research has indicated the importance of considering the broader use contexts of IT products, and, more specifically, VR products [9,10,18]. Research has suggested that it is the function and use of the VR product that are important [9,10]. However, not much attention has been given to what aspects of the VR presentation are relevant in the different phases of the building process. In the early architectural phase it is important that the experience of the VR model is as close as possible to the real building or environment when built. A faithful rendering of the appearance of the future building is desired and the feeling of being present may be important. During the construction phase, however, the feeling of being present may not be that important. During this phase the user wants to see, for instance, when different building activities need the same working space at the same time or when installations will collide.

Below is a presentation of previous research on the use of VR in the different phases of the building process. Some examples are taken from the field or from research and show how VR applications have been used or can be used in different phases. Finally, we describe the focus of our study.

1.1. Previous research on VR in the building process

The building process can be divided into the following phases: urban architecture—planning, construction and building management and maintenance. Below are some examples of how VR can be used in the different phases.

1.1.1. Urban planning

Manoharan et al. and Caneparo [3,17], discussed the use of VR in urban planning. Manoharan [17] presented a system where it is possible for the parties involved in the planning process to interact via the Internet in a collaborative virtual environment. They concluded that better-informed decisions will increase the confidence of the public in the urban development process and that if this is achieved the production process will be faster.

Caneparo [3] presented the implementation of a shared VR model on the Internet applied to a 300 million project in central Turin, Italy. The implementation not only includes designs and prototypes but all the documentation, accessible using VR. Caneparo concluded that the shared virtual environment proved to be a powerful tool for different activities, such as collaborative design, to examine and discuss the design and technological solutions as well as the management of construction information.

1.1.2. Architecture—planning

Frost and Warren [5] examined the use of VR in the architectural design process as part of the planning of a work area in a new chemical laboratory. VR was found to enable untrained participants to see and understand things they would not have been able to understand using traditional presentation tools. Examples are cases where the volume of spaces, sight lines, heights of windows and furniture overlapped with each other. They concluded that VR could be an efficient design tool in what they characterise as *process architecture*, i.e. the collaborative engagement of all stakeholders in a task environment that integrates professional tasks and architecture.

Campbell [2] investigated the use of the Virtual Reality Modelling Language (VRML) and World Wide Web (WWW) in the communication of construction documents in the final phase of architectural building design. He concluded that the VRML model could convey information in ways not possible using 2D drawing media.

A construction industry survey conducted in the UK concerning the use of visualisation tools was presented by Ganah et al. [6]. The results showed that traditional methods and tools, such as 2-D drawings, face-to-face meetings, written statements, telephone and fax, were the most commonly used methods for communication between design and site teams. The use of computer visualisation and communication were very rare. The survey also showed that the respondents estimated that delays and lack of adequate information during the construction process could account for up to 30% of the total delay.

A comparison between a VR-based feasibility study of evacuation time and a traditional calculation of evacuation time showed considerable differences in selecting routes with and without smoke in the area [21]. An important reason is that traditional calculation methods do not include the effect of visibility. The authors concluded that the VR simulation could help the designers appreciate what a building looks like under hazardous conditions. This may lead to design changes that the designers would never have thought of, if they had only considered the plans under ideal conditions.

1.1.3. Construction

Kim et al. [12] reported on the use of 4D-VR in the context of the construction of a 27-storey apartment and commercial store building project in South Korea. The 4D-VR system was found to improve communication between managers and workers and helped to decrease the initial time schedule of 43 months to 39 months.

Woksepp [24] described the use of VR on a large construction site for a hotel and office complex in Göteborg, Sweden. The VR model was available on the construction site through two PC computers. The information flow on the construction site was felt to be unsatisfactory and the use of VR was considered to be a means of improving the information flow. When asked to express agreement or disagreement with the statement: "I think it would be of benefit to me to use VR models in my work" the respondents scored 4.30 on a five-point-scale (where 5 meant "Strongly agree" and 1 meant "Disagree").

In a study by Staub-French [22] the use of 4D models was said to improve learning and communication and to help identify conflicts and logical mistakes. A conflict could, for example, be caused by two activities needing the same work area at the same time. Furthermore, when discovered in the VR model the conflict could be dealt with before it occurred in reality. Workspace at the construction site is a resource that needs to be shared.

In a paper by Zang et al. [26] it was argued that space on the construction site is an important construction resource, as are time, labour, material, etc. The authors presented a 4D construction site management model with 4D visualisation capability for the construction facilities layout. The model supported the use of site space and intelligent decisions based on a knowledge base. The authors concluded that through a visual simulation, even non-professionals may gain a clear understanding of the site management process.

The use of 4D modelling at a factory for precast concrete is described in Rönnblad et al. [19]. The biggest gain was achieved in the factory and involved better planning, less scrapping and a more effective use of existing resources. An analysis showed that the investment in 4D would be paid back within 1 year.

1.1.4. Building management and maintenance

Khosrowshahi [11] addressed maintenance problems. The research provides a visual approach to maintenance programmes that avoids two possible pitfalls in other maintenance programmes. The first is that maintenance is performed too early and the second that it is performed too late. A 4D visual model of building degradation over time was presented, where the degradation is influenced by several factors, such as the fabric of the material, the environment, the period of usage, etc. The visualisation showed the degradation of the building flooring systems during use.

As noted above, the research literature has, generally speaking, tended to discuss desirable properties of VR as such, without relating this to what is useful in the specific use context. The literature on VR has, for example, tended to regard the experience of presence as generally important for performance [13,16]. However, there are also contrary views, see e.g. [20]. In general, when a usability perspective that relates to the concrete use context is adopted, the general importance of presence can no longer be taken for granted. Similarly, how much effort it is relevant to spend on producing realistic shadowing and the degree the model is improved by additional "filling out" of details (i.e. to increase the amount of detail in the model) is likely to depend on the specific context of use.

In the present research we focus on how a VR model showing the exterior and interior of an office building that was about to be built was experienced in a use context, where the participants (who were employees at the company that was to move into the completed building) were to decide which of three types of office they would prefer to work in.

The present study also considers the extent to which the user of a VR model in the later stages of the architectural planning process could fulfil the task of choosing a preferred office type and acquire the necessary information from the model without a complete sense of presence [9]. Moreover, we investigated the extent to which it is necessary for the decision-maker (the user) to manipulate the VR model directly in order to feel that the VR model is helpful in the decision-making process in the aforementioned context, or if it is sufficient simply to have control authority? Furthermore, the empirical results in this study concern the extent to which different users experience the VR model as a useful aid in their decision-making processes.

In situations where the user is to make decisions with regard to preferences for different versions of features in the final building on the basis of the VR model, it is clearly of interest to compare the similarity between the different categories of user experience of the VR model and the same categories of user experience of the completed building. Such a comparison is reported in Study 2 of the present investigation.

When using VR models as communication tools, such as in the late stages of the design and construction of buildings, it is important that the lay person and the professional can communicate well in the intended area. One final aim of the present study was to analyse to what extent lay persons who have experienced the VR model consider it to have given an appropriate rendering of the completed real building after they have had the possibility to experience it.

This study thus focuses on the usability of VR as a tool in a decision-making process. The aim is to study how the VR model and specific aspects of it were experienced as such and as an aid in a decision-making process. The results of this study are intended to contribute to the improvement in the usability of VR models in the use processes analysed.

2. Study 1

In Study 1 we investigated the respondents' assessments of the usability of the VR model, e.g. in the form of extracting useful information from the model.

2.1. Method

2.1.1. Participants

Ninety-nine persons, 75 men and 24 women, employed at Ericsson and who were to have their future offices in the building shown in the model, took part in the VR presentations. The respondents' ages ranged from 21 to 62 years, with an average of 36 years (S.D. = 8.0, median 35).

The average level of education in the sample was 3.2 (S.D. = 1.1, median 4) as measured on a 5-point scale, where 1 represented no university studies, 2 studies at university level but no degree, 3 and 4 university degrees on different levels and 5 education on the doctoral level.

The average computer experience in the sample was 5.3 (S.D.=0.6, median 5), as measured on a 6-point scale (1 representing no computer use and 6 represented persons who were involved in developing computer software). This indicates a high level of computer experience. Everyone used computers at least once a day. No statistically significant gender differences were found for any of the three variables: age, education and computer experience.

2.2. Materials

2.2.1. The VR model

The construction of the VR model of Ericsson's new office building shown to the participants was the result of collaboration between the Visualisation Studio at Chalmers Lindholmen and Ericsson Mobile Data Design. It was built at the Visualisation Studio at Chalmers Lindholmen and shows the exterior environment, the Norra Älvstranden area in Göteborg, Sweden, where the planned Ericsson Mobile Data Design office building is to be located. It also shows the interior of the planned building, with its workplaces, furniture, some static image representations of staff (bill-boards) at the company (including the CEO) and so on. The VR model was built in 2001 and the building was constructed and completed in 2003. Fig. 1 shows an example of each of the internal and external VR models of the office building.

The internal model includes visualisations of three different office layouts in different parts of the building. The three office types were landscape (no separating walls between desks), traditional (separating walls between desks) and mixed. The three office types as shown in the VR model are illustrated in Fig. 2a–c. The layout of the same three office types is illustrated in the form of blueprints in Fig. 2d–f.

The model has been used successfully as a tool in the commercial process to plan the whole area as well as the specific working environment at Ericsson. During the construction of the VR model, the chief architect responsible for the planning of the building participated in weekly meetings at which the colours, form and experience gained from the model were discussed from the point of view of the architect's visions.

2.2.2. Technical equipment used for programming the model and for the shows

The technical equipment used at the shows was a Silicon Graphics Onyx2 computer and a powerwall. The direct distance from the left to the right of the powerwall was 4.81 m and the distance from the middle of the concave to the middle of the aforementioned distance was 0.35 m. The concave was 1.97 m high. The distances from the middle of the concave to the three rows of chairs were 3, 4 and 5 m respectively.

A 3D-effect was achieved by using Crystal Eyes, i.e. stereo glasses. The programs used for the construction of the model were MultiGen Creator and 3D Studio Max. The model was then visualised in a program developed in-house and based on OpenGL Performer.

The lightning effect was achieved by using an ambient and diffuse light source. Some local shadow effects were achieved by photos and pre-rendered images described in [25] as primary ore attracted shadow. In the external VR model, simple shadow models were used for shadow casting from the trees, described in [25] as derived ore cast shadow.

2.2.3. VR experience questionnaire

A questionnaire was developed and included general questions about the VR experience at the VR shows. The

Fig. 1. Examples from the internal and external VR models.

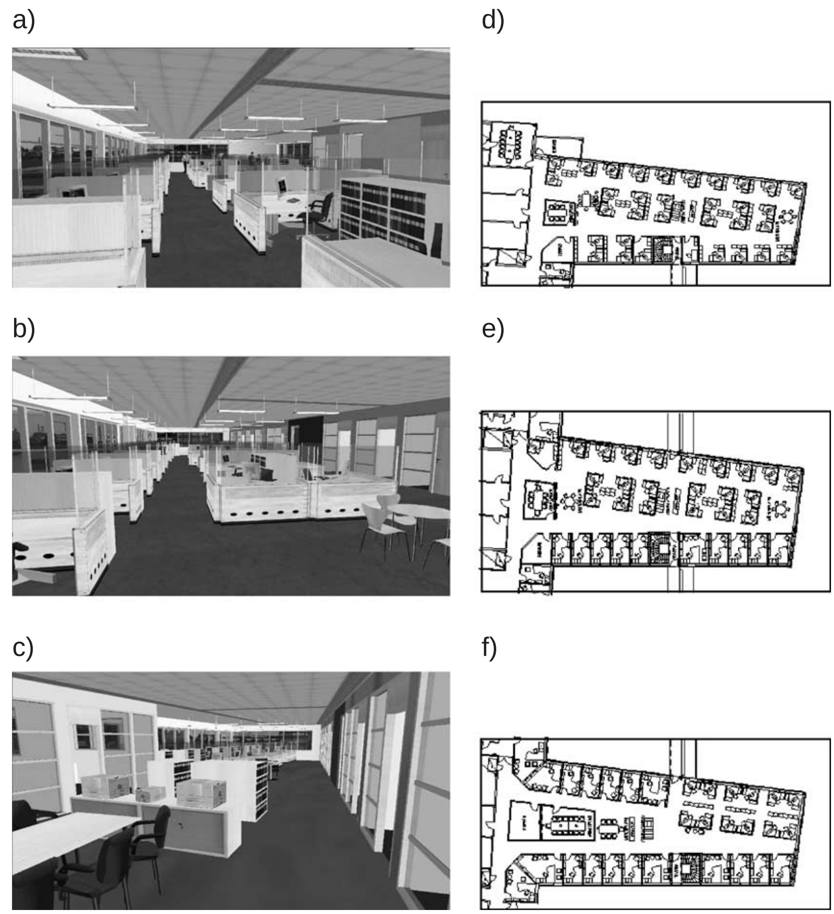

Fig. 2. a–c. The three office types as shown in the VR model, a) landscape, b) mixed, and c) traditional. d–f. The layout of the same office types shown as blueprints, d) landscape, e) mixed, and f) traditional.

topics covered the extent to which the model was useful as a tool in understanding how the respondents' future work environment would appear and the extent to which various aspects of the model felt real. Most of the questions in the VR questionnaire were answered on a seven-step scale with 1 = "Not at all" and 7 = "Totally". The non-qualitative questions are presented in Table 1. A few of the questions were open-ended questions and are presented in the Results section.

2.3. Procedure

The VR shows in 2001 took place at the Chalmers Lindholmen Visualisation Studio. The participants were to have their future workplaces in the building depicted in the VR model. In the studio the VR model was shown on a powerwall.

Each VR show in 2001 was introduced by the Chief Executive of the company, who welcomed the participants to "an inspiring journey into the virtual world showing your future office". First, the exterior environment around the building was presented with a spoken commentary lasting about 20 min. One reason for this part was to acquaint the participants with the VR presentation. Next, a guided tour of the interior of the building followed, lasting about 15 min, first showing the ground floor of the building. The design of the interior was formed by the company's branding policy ("company image"). The participants saw the reception, restaurants, etc., located on the ground floor. They then saw the landscape office, followed by the two other office types (traditional and mixed) on the second floor of the building. During the show, the researchers directed the model although the commentator and participants could request to see any particular part of the model again. The VR experience questionnaire was filled in after the whole VR presentation had been completed.

A total of 10 groups, varying between 9 and 30 persons, saw the VR shows (for design reasons only the results for a sub-group (99 persons) are reported here). All participants selected the specific group they were part of by voluntary choice of occasion.

2.4. Results

Table 1 shows the means and standard deviations for the non-qualitative questions in the questionnaire.

Initially, it can be noticed that most of the respondents thought that the VR model had given them a fairly good

Table 1
Means (S.D.s) for the non-qualitative questions

Variable/question	Mean (S.D.)
1. Did you feel the VR model lacked information for you to understand how you are going to experience your future work environment? (No = 0, Yes = 1; $n = 98$)	0.59 (0.49)
2a. To what extent do you feel the internal environment VR model has given you an understanding of what your future working environment is going to look like?	5.22 (0.92)
2b. To what extent do you feel the external environment VR model has given you an understanding of what your future working environment is going to look like?	5.21 (1.07)
3. Would you be able to make decisions about your future internal workplace using the VR model as a base?	5.11 (1.07)
4. Did the surfaces (such as walls, floors and roofs) feel real in the internal VR model?	4.75 (1.29)
6a. Could you orient yourself in the internal environment during the VR show?	5.42 (1.29)
6b. Could you orient yourself in the external environment during the VR show?	5.37 (1.45)
7a. Did the shading in the internal environment model feel real? ($n = 94$)	4.53 (1.18)
7b. Did the shading in the external environment model feel real? ($n = 95$)	4.62 (1.29)
8. Did the furniture in the VR model feel real?	5.19 (1.04)
9. You have seen a VR show of both an internal and external environment. Which of the environments gave the greatest feeling of experience? (Internal = 1, External = 2; $n = 95$)	1.52 (0.50)
10. Would you have wanted to walk on your own (have control yourself) in the VR model?	5.55 (1.90)
11. Did you get bored with the VR model during the show?	3.36 (1.75)
12a. Do you believe that there will be sufficient personal space in your future work environment in an office landscape?	2.67 (1.56)
12b. Do you believe that there will be sufficient personal space in your future work environment in a traditional office?	5.37 (1.43)
12c. Do you believe that there will be sufficient personal space in your future work environment in a mixed office? ($n = 97$)	3.75 (1.34)
13. Are you able to envisage how you will be able to move about during a normal day in your future working environment?	4.82 (1.31)
15. Which environment felt most pleasant in the model: a traditional office or an office landscape? (coded as traditional = −3 to landscape = 3)	−1.21 (2.08)
16a. Indicate the extent to which you think the following factor influenced your reply to question 15: Experience from earlier working environments.	5.64 (1.72)
16b. Indicate the extent to which you think the following factor influenced your reply to question 15: The VR model.	4.30 (1.72)

Unless stated otherwise, the question response format was a scale with steps from 1 to 7 ($n = 99$).

understanding of what their future workplace would look like (2a, 2b)[4]. This applied to both the internal and the external environment (M = 5.22 and M = 5.21, respectively, on a scale where 1 = "Not at all" and 7 = "Totally"). They also tended to feel that they would be able to make decisions about their future internal workplace using the VR model as a base, M = 5.11 (3).

The frequencies and strength in the preferences for traditional offices or office landscapes are presented in Fig. 3. Most respondents preferred the traditional office.

Of the 99 respondents, 40 reported that they thought that the VR model did not lack any information although 58 respondents thought it did (1). (One person did not answer this question.) Moreover, the respondents felt to a fairly high degree that they could orientate themselves in both the internal and external model ($M = 5.42$ and 5.37 respectively) (6a, 6b). The results for the remaining questions are shown in Table 1.

2.5. Individual differences

Next we present the bivariate correlations between the five background variables, age, gender, vision defects, education and computer experience on the one hand and the non-qualitative questions on the other. Significant correlations were only found for education and computer experience. The results for the significant correlations are shown in Table 2. Because of the potential mass-significance problem, we use the convention of only reporting correlations where $p < 0.025$.

The results for *education* showed that respondents with higher education reported more often that they became bored with the model (11), $r = 0.341$, $p < 0.001$. The respondents with higher education also tended to feel that the personal space in the office landscape was insufficient (12a), $r = -0.292$, $p < 0.003$. Finally, higher education was associated with the feeling that the choice between the traditional office and the office landscape type was influenced less by their prior knowledge (16a), $r = -0.257$, $p < 0.010$.

The results for *computer experience* showed that the external environment of the model appears to have worked less well for more experienced computer users. For example, respondents with more computer experience tended to feel that the external environment in the VR model had given them less understanding of their future work environment (2b), $r = -0.234$, $p < 0.020$, and they also tended to feel less able to orientate themselves in the external VR environment (6b), $r = -0.229$, $p < 0.022$. In addition, more computer experience was associated with becoming more bored with the model during the shows (11), $r = 0.247$, $p < 0.014$. Finally, more computer experience correlated with a lesser tendency to assert that it was prior

[4] The numbers in brackets refer to the questions in Table 1.

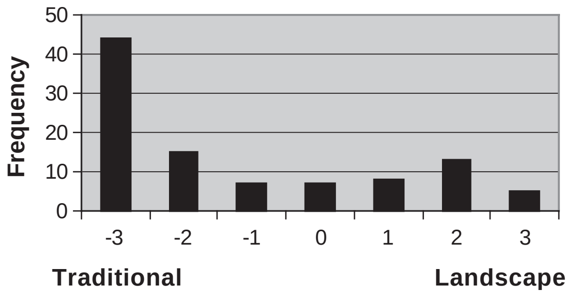

Fig. 3. Numbers of respondents preferring a traditional office or an office landscape. (−3 indicates a total preference for a traditional office and 3 indicates a total preference for an office landscape.)

knowledge that influenced the choice between the traditional office and the office landscape (16a), $r = -0.317$, $p < 0.001$.

2.5.1. Correlations between the different questions in the questionnaire

Below is a report on the correlations between the non-qualitative questions in the VR questionnaire. For reasons of space the correlations involving questions 12a, b, and c will not be reported in the text or in Table 3. The remaining correlations are shown in Table 3. The convention used in Table 2 for selecting correlations is also followed in this table. The most relevant correlations in Table 3 are described next.

The feeling that the VR model of the internal environment had given the respondents an understanding of what their future workplace would look like (2a) correlated with some of the other variables. For example, this variable (2a) correlated with the feeling that the VR model of the external environment had given the respondents an understanding of what their future workplace would look like (2b), $r = 0.376$, $p < 0.000$. The same variable (2a) also correlated with the feeling of being able to make decisions about the internal workplace on the basis of the VR model (3), $r = 0.390$, $p < 0.000$, and with the feeling that the furniture in the model was real (8), $r = 0.233$, $p < 0.020$.

Reporting that the VR model of the external environment had provided an understanding of what their future workplace would look like (2b), correlated with the feeling of being able to orientate oneself in the external environment (6b), $r = 0.409$, $p < 0.000$, as well as the feeling that the shading in the external environment was real (7b), $r = 0.293$, $p < 0.004$. Moreover, the variable (2b) also correlated with reporting that the external environment, compared with the internal environment, had the greatest experiential impact (9), $r = 0.413$, $p < 0.000$ (Spearman).

Respondents who reported that the surfaces in the internal environment were experienced as being realistic (4) also felt that the furniture was realistic (8), $r = 0.357$, $p < 0.000$.

The feeling of being able to orientate oneself in the external environment (6b) correlated positively with the feeling of being able to orient oneself in the internal environment (6a), $r = 0.473$, $p < 0.000$. The same feeling of being able to orientate oneself in the external environment (6b) also correlated with the feeling that it was the external environment that gave the greatest feeling of experience (9), $r = 0.364$, $p < 0.000$ (Spearman).

Reporting that the shading/shadows were correct in the internal environment (7a) correlated with the feeling that the shading/shadows were correct in the external environment (7b), $r = 0.612$, $p < 0.000$. It also correlated with the feeling that the furniture in the VR model was realistic (8), $r = 0.311$, $p < 0.002$.

2.5.2. Content analysis of the open-ended questions

The content analysis of three questions with open-response modes was made by coding the responses into different categories. Two independent teams with two persons in each team coded the responses. The inter-judge reliability between the teams, i.e. the percentage of all the codings that were the same for both teams, was computed for each question. Most of the discrepancies between the coding teams occurred when one team used the *Other* or the *Nothing* categories and the other team used a more specific category. The results reported below reflect the items where both teams gave the same codings.

One of the three open-ended questions to be reported was If you felt information in the VR model was missing, state what information you would have wanted. In this coding a specific respondent could be coded into many categories. The results can be found in Table 4 and showed that the largest category was *Sound*, mentioned by 36 respondents. Another large category was *Missing details*(referring to "details" or "physical details"), mentioned 30 times. Other frequent responses are shown in Table 4. Seventeen responses were coded as relating to *Other* information. The inter-judge reliability between the two coding teams for this question was 74%.

The second open-ended question was You have chosen one of the external or internal environments as having the greatest experiential impact. What was the reason for your choice? The results are shown in Table 5. The largest category was Number of details, with 26 responses (18 internal and eight external environments), followed by Involvement (defined as involvement in the design of the respondent's own specific workplace), eight responses, and Overview-orientation-connectedness, seven responses. The inter-judge reliability for this question was 71%.

Table 2
Correlations with p values < 0.025 between some background variables and questions in the VR questionnaires

Variable	2b	6b	9	11	12a	16a
Education				0.34 (0.001)	−0.29 (0.003)	−0.26 (0.010)
Computer experience	−0.23 (0.020)	−0.23 (0.022)	−0.23 (0.024)	0.25 (0.014)		−0.32 (0.001)

p values are given in brackets. The numbers in the first row refer to the questions in Table 1.

Table 3
Correlations between questions in the VR questionnaire

Question	2b	3	6b	7b	8	9	13	15	16a	16b
2a	0.38 (0.000)	0.39 (0.000)			0.23 (0.020)					
2b			0.41 (0.000)	0.29 (0.004)		0.43 (0.000)				
3										
4					0.36 (0.000)					
6a			0.47 (0.000)							
6b						0.36* (0.000)	0.25 (0.014)			
7a				0.61 (0.000)	0.31 (0.002)					
7b					0.35 (0.000)					
9	0.41* (0.000)									−0.25 (0.016)
10								0.27 (0.007)		
15									−0.33 (0.001)	

The p values are given in brackets. The numbers in the left-hand margin and in the first row refer to the questions in Table 1.
* Spearman.

The third open-ended question was What details were important in forming an opinion of the size of the room? The results are shown in Table 6 and showed that *Furniture*, with 50 responses, was the largest category, followed by *People* (39 responses). The inter-judge reliability for this question was 80%.

2.6. Discussion

In brief, this study showed that the respondents felt that the VR model provided some valuable information. Moreover, the correlations between the answers to the questions in the VR experience questionnaire showed consistent patterns. Importantly, for example, the feeling that the internal environment of the model had provided an understanding of what their future workplace would look like correlated with the feeling that the VR model of the external environment had given the respondents an understanding of what their future workplace would look like and with the feeling of being able to make decisions about the internal workplace on the basis of the VR model.

In general, the significant correlations showed a pattern that indicated that the participants' experiences of the different parts of the model were well integrated. For example, feeling able to orientate oneself in the external model correlated with the corresponding feeling in the internal model, and the feeling that the shadows were correct in the external model correlated with the feeling that the shadows were correct in the internal model.

Table 4
Information felt to be missing in the VR model

Category	Number of responses	Comment
Sound	36	
Missing details	30	Refers to "details" or "physical details"
Rendering of light in the model	15	
Functional areas	14	
Social life	12	
Traces of social activity	8	
Viewing features	5	
Other	17	

The study also gave some indication that earlier experience influences how the model was experienced. Computer experience, for example, correlated significantly and negatively with the feeling of being able to orientate oneself in the model. This means that more computer experience made it feel more difficult to orientate oneself in the external VR model. Moreover, the VR model experienced by the respondents did not fulfil all the conventional criteria for providing a high degree of presence. In spite of this, they felt that the model was useful.

3. Study 2

The second study aimed to investigate further some of the questions raised in the first study. The most important issue in the second study was whether there were any indications that the VR model provided information that was useful to the respondents. In the context of choosing an office type, an indication of usefulness is that the experience of the environment in the model and the experience of the real building should be almost the same. Another indication of usefulness is that it is possible to make predictions about the new work environment with the aid of the VR model that turn out to be true in the real work environment. An example is that it is possible to foresee in the VR model where social contact between colleagues will occur in the real building. In this second study the Semantic Environmental Description scale (SMB from Swedish "semantisk miljöbeskrivning") and a questionnaire were used to test the experience of the VR model and the real building.

3.1. Method

3.1.1. Participants

Two groups of employees at the Ericsson company participated in the study. One of these groups was studied on two occasions; first in 2001 with regard to their experience of the VR model depicted the building ($n=99$) and then 19

Table 5
Reasons for choosing one of the external or internal environments as having the greatest experiential impact

Category	Number of responses	Comment
Number of details	26	18 internal and eight external environments
Involvement	8	Defined as involvement in the design of the new workplace
Overview-orientation-connectedness	7	
Cramped feeling	2	
Social life	2	

(14 men and five women) of the 99 persons in the original 2001 group were studied again in 2003 with regard to their experience of the real building and with regard to how the VR model depicting the building compared with their experience of the real building. The average age of this group in 2003 was approximately 33 years (S.D. = 6.4, median = 32).

The second group consisted of 20 persons, who were working in the building in 2003; 15 men and five women. The average age of the respondents in this group was approximately 40 years (S.D. = 9.4, median = 41). This group had not seen the VR show in 2001 and was studied in 2003 with regard to their experience of the real building and its office landscape.

The first group's average reported computer experience in 2003 was 5.7 (S.D. = 0.6, median = 6) as measured on a 6-point scale, where 1 represented no computer use and 6 represented persons who were involved in developing computer software. The second group reported an average computer experience level of 5.0 (S.D. = 0.6, median = 5). The means (and S.D.s) for age and computer experience and frequencies for the two genders in the two groups are shown in Table 7. Finally, the level of education in the first group in 2003 was 4.0 (S.D. = 0.8, median = 4) and in the second group 3.3 (S.D. = 1.0, median = 4), measured on the same scale as in Study 1.

Significant differences were found between the two groups for age ($t = 3.03$, $df = 30$, $p = 0.005$), for computer experience ($t = -3.73$ $df = 37$, $p = 0.001$) and for educational level ($t = -2.14$, $df = 37$, $p = 0.039$).

Table 6
Details reported to be important in forming an opinion of the size of the room

Category	Number of responses
Furniture	50
People	39
Objects	13
Perspective	10
Light	6
Shadow	2

3.2. Procedure

The data from 2001 in Study 2 was collected on the same occasion as the data in Study 1. The collection procedure for the VR show was thus the same as the procedure mentioned in the Method section of Study 1 in this paper. The group took the SMB test, described below, directly after seeing the landscape office. When they answered the SMB scale they still had the model in front of them on the powerwall (with the viewer's perspective slowly rotating around one point). After the whole VR presentation had been completed the participants filled in the VR experience questionnaire, described below.

The data collection sessions in 2003 took place in the completed real building. The sessions started with a very brief walk (about 1 min) in the real landscape office, which also included a few members of staff. After the walk the participants first answered the SMB test when they were standing in the office area. The landscape office in the real building is shown in Fig. 4. After the SMB test they answered, still standing in the office area, a general questionnaire specifically developed for this study. The two groups received the same treatment, with the exception that the general questionnaire differed between the groups.

3.3. Material

The VR model and the Technical equipment used for programming the model and for the shows were the same as the model and equipment mentioned in the Method section of Study 1, above.

3.3.1. The semantic environmental scale (SMB scale)

In order to measure how the participants experienced the virtual room environments (the landscape office) and the other parts of the VR model, the SMB scale, developed by Küller [14,15] was used. The purpose of the SMB scale is to describe systematically the perceived environment. Its purpose is thus to be an aid in describing systematically how individuals experience their environment and not, for example, to measure characteristics of individuals. This is a product of many years of development aimed at systematically measuring and describing experiences of built environments [14,15]. The broader work by Osgood, Suci and Tannenbaum, published in 1957, formed the basis for the

Table 7
Means (S.D.s) for age and computer experience and frequencies for gender in the two groups

	Group 1	Group 2
	Real building 2003	
Age	33.1 (4.9)	40.0 (9.4)
Computer experience	5.7 (0.6)	5.0 (0.6)
Educational level	4.0 (0.8)	3.3 (1.0)
Gender (frequency)	F = 5, M = 14	F = 5, M = 15

Group 1 = had seen VR in 2001, Group 2 = had not seen VR in 2001.

Fig. 4. Example from the real landscape office.

SMB scale, which is limited to experience of built environments. Initial work by Küller established that when sets of a large number of adjectives were factor-analysed the adjectives clustered into eight factors, which are used in the SMB scale (see Table 8).

The SMB scale has 36 single-adjective, seven-step scales. When used to judge real world environments, the SMB reaches a high degree of stability already in group sizes of 15–20 individuals [14,15].

The SMB scale has mostly been used in real environments although Küller [14,15] suggested that it could also be used for descriptions of environments shown with the use of sketches, collages, three-dimensional models, films or TV techniques. He also noted that the SMB scale offers potential in future city planning in model form. For this reason, we chose the SMB scale to measure both the experience of a future office complex presented in VR and the experience of the real, completed building.

3.4. VR experience questionnaires

3.4.1. Questionnaire for evaluating experience of the model at the VR shows

The same questionnaire was used as in Study 1. The questions included in the present study are shown in Table 10 (a complete version of the questionnaire is given in [23]).

3.4.2. Questionnaire for evaluating the VR model compared with the real building for participants who had seen the VR show

A further questionnaire was developed to evaluate the participants' experience of the VR model as compared with how they experienced the real building. This questionnaire was given to the participants who had seen the VR model. The questionnaire included general questions about the earlier VR show in 2001 and how it related to the experience of the real building. The questions can be seen in Table 11. Again, most of the questions in the questionnaire were answered on a seven-step scale with 1 = "Not at all" and 7 = "Totally". Five of the questions were open-ended and are presented in the Results section. One of these questions asked the participants to identify natural meeting places in the building and one question asked the participants to evaluate the number of days it had taken them to get to know and to be able to orientate themselves in the new building.

3.4.3. Questions for evaluating the real building for participants who had not seen the VR show

The same two open-ended questions as mentioned immediately above were answered by the participants who had not seen the VR show and who evaluated the real building.

3.5. Results

The two groups' means and standard deviations for the different SMB factors are presented in Table 9.

In Fig. 5 the results for the SMB factors are presented as profiles. The biggest difference in the profiles for the two groups is for enclosedness. The values are higher for the group that had not seen any VR presentation.

Due to the mass-significance problem and due to space limitations, we will only report results on the level of $p < 0.025$ or which are of special interest. We first compared the SMB results with regard to the group who saw the VR show in 2001 with the results from the same group in 2003 when they evaluated the real building. A paired t-test showed a significant difference in the SMB factors Pleasantness ($t = -4.30$, $df = 18$, $p = 0.000$), Unity ($t = -2.56$, $df = 18$, $p = 0.020$) and Potency ($t = -3.58$, $df = 18$, $p = 0.002$).

Next we compared the SMB results for the VR-show in 2001 with the evaluation of the building for the group who had not seen the VR show in 2001. The t-tests computed showed significant differences for the SMB factors Enclosedness ($t = 3.77$, $df = 37$, $p = 0.001$) and Potency ($t = 3.03$, $df = 37$, $p = 0.004$). Finally, we compared

Table 8
The eight factors of the SMB scale (from [14], p. 132)

Factor	Definition
Pleasantness	The environmental quality of being pleasant, beautiful and secure.
Complexity	The degree of variation or, more specifically, intensity, contrast and abundance.
Unity	How well all the various parts of the environment fit together into a coherent and functional whole.
Enclosedness	A sense of spatial enclosure and demarcation.
Potency	An expression of power in the environment and its various parts.
Social status	An evaluation of the built environment in socio-economic terms, but also in terms of maintenance.
Affection	The quality of recognition, giving rise to a sense of familiarity, often related to the age of the environment.
Originality	The unusual and surprising in the environment.

Table 9
Means (S.D.s) for the SMB factors for the different groups in the study

SMB factor	VR model 2001	Real building 2003	
	Group 1 ($n=19$)	Group 1 ($n=19$)	Group 2 ($n=20$)
Pleasantness	3.30 (1.22)	4.49 (1.15)	3.79 (0.91)
Complexity	4.29 (1.16)	4.19 (1.00)	3.78 (0.66)
Unity	5.00 (0.87)	5.48 (0.72)	5.30 (0.60)
Enclosedness	2.29 (0.98)	2.19 (0.63)	3.53 (1.06)
Potency	4.18 (0.55)	4.72 (0.70)	4.69 (0.49)
Social status	4.14 (1.18)	4.25 (1.27)	3.59 (1.14)
Affection	2.79 (1.10)	2.37 (0.65)	3.09 (0.70)
Originality	3.82 (1.05)	3.89 (1.14)	3.25 (0.85)

the results for the SMB factors for the group who had not seen any VR show earlier and the evaluation of the building made by the group who had seen a VR show. This comparison showed significant differences in Enclosedness ($t=4.74$, $df=37$, $p=0.000$) and Affection ($t=3.32$, $df=37$, $p=0.002$).

When computed for the two groups in 2003, the background variables correlated significantly with some of the SMB factors. Age correlated with Complexity ($r=-0.35$, $p=0.034$) and Enclosedness ($r=0.33$, $p=0.049$). Computer experience correlated with Enclosedness (Spearman's $r=-0.38$, $p=0.016$).

3.6. VR questionnaire 2001

Table 10 presents the results of the VR questionnaire for the group that visited the VR show in 2001. In this table, only the answers from the respondents that participated in the study in 2003 are included. In Table 1, all the respondents from 2001 are included.

One interesting result is that the respondents reported that the VR model had given them a fairly high understanding of what their future work environment would look like; both the internal environment (1), mean 4.95, and the external environment (2), mean 5.26. Another interesting result was that the respondents reported that they felt to a rather high extent that they would be able to make decisions about their future workplace using the VR model as a base (3), mean 5.26.

Table 11 presents the questionnaire results for the evaluation of the real building for the group who had seen the VR show in 2001. It is interesting to note that the respondents reported that the earlier VR shows had given them a fair impression of the new work environment to a rather high degree (mean 5.37, S.D.=0.95). This corresponds with the respondents' assessment that the internal and external environment corresponded with the real internal environment (2), mean 5.16, and external environment (3), mean 4.26.

All participants were asked to estimate how many days it had taken to learn to orientate themselves and get to know the building. On average, the estimated time was 5.31 days (S.D.=9.61). For the group who had not seen the VR show earlier, the estimated average time was 7.00 days (S.D.=12.96) and for the group who had seen the VR show earlier the estimated average time was 3.53 days (S.D.=3.32). This difference, although interesting, is not significant.

3.6.1. Content analysis of the open-ended questions

The group who had seen a VR show in 2001 were asked five open-ended questions in 2003 concerning their reac-

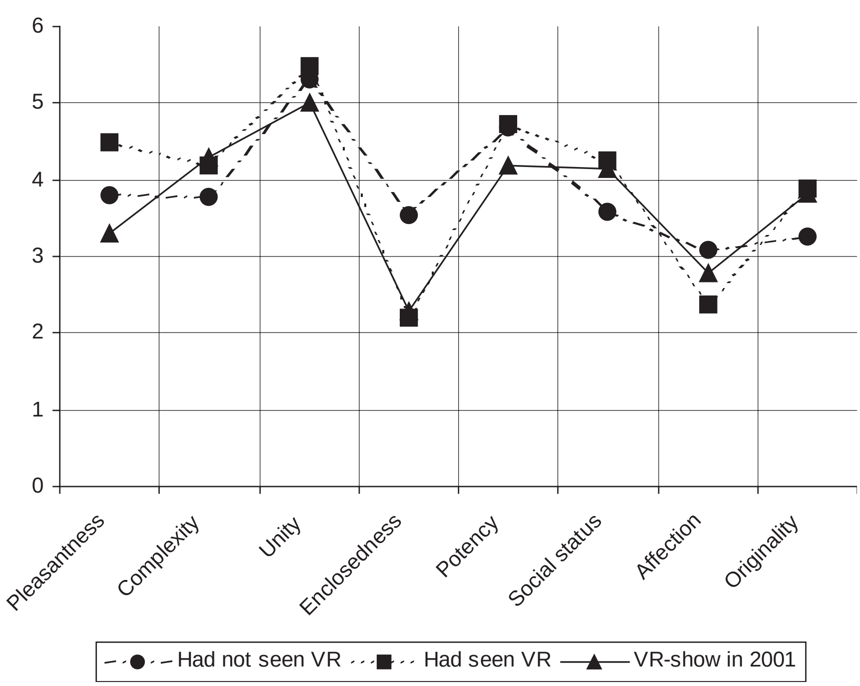

Fig. 5. Results for the eight SMB factors for the different groups in the study.

Table 10
Evaluation of the VR show 2001

	Question	Mean (S.D.)
1	To what extent do you feel the internal environment VR model has given you an understanding of what your future working environment is going to look like?	4.95 (0.91)
2	To what extent do you feel the external environment VR model has given you an understanding of what your future working environment is going to look like?	5.26 (0.872)
3	Would you be able to make decisions about your future workplace using the VR model as a base?	5.26 (1.05)
4	Did the surfaces (such as walls, floors and roofs) feel real in the VR model?	4.37 (1.71)
5	Could you orientate yourself in the internal environment during the VR show?	5.58 (0.96)
6	Could you orientate yourself in the external environment during the VR show?	5.84 (1.42)
7	Did the shading in the internal environment model feel real?	4.37 (1.50)
8	Did the shading in the external environment model feel real?	4.68 (1.45)
9	Did the furniture in the VR model feel real?	5.0 (1.41)
10	Would you have wanted to walk on your own (control things yourself) in the VR model?	5.58 (1.46)
11	Did you get bored with the VR model during the show?	3.89 (1.76)
12	Are you able to foresee how you will be able to move on a normal day in your future working environment?	4.68 (1.25)
13	Which environment felt most pleasant in the model, a traditional office or an office landscape? (coded as traditional = −3 to landscape = 3)	−2.11 (1.73)
14	Indicate the extent to which you think the factor below influenced your answer. Experience from earlier working environments.	5.74 (1.66)
15	Indicate the extent to which you think the factor below influenced your answer. The VR model.	4.42 (1.68)

Mean (S.D.) for some questions in the in the VR questionnaire 2001 ($n = 19$).

tions and thoughts about the VR model they had seen in 2001. The respondents were allowed to give several responses to each of these questions.

The content analysis of five questions with open-response modes was done in the same manner as in Study 1. Most of the discrepancies between the coding teams occurred when one team used the Other or the Nothing categories and the other team used a more specific category. The results reported below reflect the items where both teams gave the same codings.

The first question dealt with whether they now, in 2003, felt that any information was *lacking* in the model that they had seen in 2001. There were 12 responses, given by nine respondents, to this question. Three responses concerned different *details* in the model that the respondents thought could be better, such as details in the *view out of the windows* in the building and objects in the internal environment, such as pencils and pens that one usually finds in a workplace. Two of the responses concerned the *light* in the model, such as how different types of sunlight influenced the environment. Two responses were about *sound*, such as how different layouts in the model would influence the sound formation. Three responses were coded as *Other*. One of these concerned navigation support. This

Table 11
Evaluation of the real building

	Question	Mean (S.D.)
1	Do you experience that the shows depicting your new work environment gave a fair impression?	5.37 (0.95)
2	To what extent do you feel the virtual internal environment corresponds to the real internal environment?	5.16 (1.17)
3	To what extent do you feel the virtual external environment corresponds to the real external environment?	4.26 (1.69)
4	To what extent do you feel the internal VR model gave you an understanding of your future work environment?	5.05 (0.78)
5	To what extent do you feel the external VR model gave you an understanding of your future work environment?	4.58 (1.68)
6	To what extent do you feel the virtual environment corresponds to the real environment with regard to office landscapes?	5.16 (1.01)
7	To what extent do you feel the virtual environment corresponds to the real environment with regard to traditional offices?	4.22 (1.35)
8	To what extent do you feel the virtual environment corresponds to the real environment with regard to mixed offices?	4.50 (0.99)
9	To what extent do you feel the virtual entrance gate corresponds to the real entrance gate?	4.63 (1.42)
10	To what extent do you feel the internal VR model gave a feeling of the size of your new work environment?	4.42 (1.30)
11	To what extent do you feel the external VR model gave a feeling of the size of your new work environment?	4.58 (1.71)
12	To what extent do you feel the surfaces in the internal VR model correspond to the real surfaces?	4.37 (1.46)
13	To what extent do you feel the VR model has made it easy for you to orientate yourself in the external environment?	4.32 (1.89)
14	To what extent do you feel the VR model has made it easy for you to orientate yourself in the internal environment?	3.84 (2.01)
15	To what extent do you feel the shading in the VR model corresponds to the real external environment?	4.00 (1.28)
16	To what extent do you feel the shading in the VR model corresponds to the real internal environment?	4.17 (1.58)
17	Do you move in your environment as you thought you would as seen from the VR model?	3.44 (1.50)
18	How well do you remember the VR model?	5.33 (2.28)

Questionnaire results (Means and S.D.s) for the group who had seen the VR show in 2001 ($n = 19$).

response asked for a mark showing the viewer's place in the model. One of the other responses concerned the feeling of height in the model. The inter-judge reliability for the coding of this question was 80%.

The second question with an open-ended response mode was if the respondents were of the opinion that there were aspects of the work environment that were given a *fair presentation* in the model. There were 17 responses to this question given by 17 respondents. Of these responses, eight concerned the layout, space and location of different facilities in the house, two concerned the colours in the model, seven responses expressed that the model had a fair degree of resemblance to the real building and/or environment. The inter-judge reliability for the coding of this question was 85%.

The third open-ended question was if there were aspects of the work environment that were given a *misleading* presentation in the model. There were 15 responses to this question, given by 11 respondents. Of these responses, four referred to the depiction of different sizes in the model, such as the length of corridors in the building. Three responses concerned details such as the view out of the windows. Three responses concerned special places, such as laboratories that existed in the real building but were not shown in the model. Five responses were coded as *Other* information. One example is that the light in the model felt unnatural. The inter-judge reliability for the coding of this question was 100%.

The fourth open-ended question was whether there were any aspects of the VR model that the respondents felt could be *improved*. There were 18 responses to this question from 13 respondents. Three responses corresponded to light in the model. Three responses concerned sizes in the model, such as the size of the workplaces. Three responses wanted the model to contain more details, such as personal belongings. Two responses concerned the view out of the windows. Two responses referred to the lack of naturalness of how the movements between different places in the model were controlled. Five responses were coded as *Other*. One of these responses wanted sound in the model, one wanted to control the movements in the model and one wanted less sterile surfaces. The two remaining responses contained no suggestions for improvements. The inter-judge reliability for the coding of this question was 95%.

Table 12
Natural meeting places discovered in the VR show in 2001 and in the real building in 2003

Category	Group 1 2001 ($n=19$)	Group 1 2003 ($n=19$)	Group 2 2003 ($n=20$)
Places planned for the employees' breaks and coffee drinking	14	19	18
Corridors	6	7	5
Office landscapes	4	7	6
Traditional offices	0	4	7
Restaurants	3	3	6
Entrance gate	1	2	4
Other	0	3	3
Total	28	45	49

The final open-ended question concerned *natural meeting places* that had been discovered in the real building. This question was given to both groups when they evaluated the real office landscape in 2003. The same question was also given to Group 1 after the VR show in 2001. The coding of these responses is shown in Table 12.

As can be seen in the two right-hand columns in Table 12 there are no important differences in 2003 between Group 1 and Group 2. The VR show thus appears not to have influenced the experience of the real building.

We next turn to a comparison of Group 1 after the VR show in 2001 ($n=19$) and the experience of the same group of the real building in 2003. Again the comparison (second and third row in Table 12) shows no major differences. The most common category concerned places that were planned for the employees' breaks and coffee drinking. Differences could be seen, however, in the office landscape and traditional office categories. A speculation is that these differences could to a large extent be explained by the "cramped feeling" mentioned in Table 5 for the offices. Such a cramped feeling may have made it difficult to discover meeting places. Finally, in 2003 both groups identified slightly more meeting places in the house than the VR-group discovered in 2001.

In brief, the VR model made it possible to identify some, but not all, of the meeting places that are identified in the house today. The inter-judge reliability for the coding of this question was 90%.

4. General discussion

Our study analysed the usability of a VR model depicting the exterior and the interior of an office building. The use context for the VR model was the last stage of a real-life architectural planning process, the stage where the staff of the company that would occupy the building was to select the type of offices they were to work in.

Below, we discuss the results with regard to indications of the VR model's usability and then discuss results that suggest that the VR model did in fact give veridical information about how the real building was experienced. Thereafter, we discuss how the usability of VR models in the later stages of the architectural planning process could be improved without investing resources in perfecting the properties of the VR model on all fronts. Finally, we consider how the VR experience may have affected the experience of the real building.

Overall, the results indicate that the VR model was felt to be useful as an aid in making the described decision. This is indicated by the fact that the respondents on average gave a rather high rating concerning the possibility to make decisions about their future internal work environment using the VR model as a base, as well as the fact that they generally gave high values when rating their level of understanding of their future work environment provided by the VR model. The participants also gave fairly high values for the degree to which the various aspects of the VR model asked about felt real.

That the VR model did in fact give veridical information about how the real building was experienced can be understood by relating the results in studies 1 and 2. It was found that the social meeting places in the building identified by the respondents after having seen the VR model in 2001 were approximately the same as the ones identified in the real building by the same respondents in 2003. It was thus possible for the respondents to foresee natural meeting places in the model. In addition, the respondents did not discover substantially more or different meeting places in the real building. There were only a few places, such as landings, that were illustrated in the VR model and which were not mentioned in 2001 after the VR show but which were mentioned in the evaluation of the real building. There were also a few places that were added in the evaluation of the real building that were not illustrated in the VR model. Overall, these results indicate that the model provides fairly good potential to foresee social places, i.e. social interaction, in the VR model. A further indication that the VR model helped the participants to foresee social areas in the real building is that there were no major differences in the stated meeting places between the group who had seen the VR shows and the group who had not.

Another indication of the model's veridicality is that the results for the SMB scale showed a fairly high degree of similarity with regard to the experience of the VR model in 2001 and how the same group of people experienced the real completed building in 2003. However, the values for the three factors *pleasantness*, *unity* and *potency*, differed between the experience of the VR model and the experience of the real completed building. In each case, the value was higher for the real building. However, although these differences were significant they were smaller than one scale unit, except for the pleasantness factor. In brief, the VR model can be said to have given a fairly good rendering of the participants' experience of the, at that time, uncompleted building. However, it is notable that the VR model appeared to be lacking somewhat in the communicated degree of pleasantness of the building.

A comparison between the SMB results in 2001 for the group that had just seen the VR show and in 2003 for the group that had not experienced the VR model revealed two differences, one fairly substantial, relating to enclosedness and the other, rather small, to potency. Here it is relevant to consider first that age differed significantly between the two groups and second that the correlation between age and enclosedness for these two groups was marginally significant ($r = 0.31$, $p < 0.062$). Likewise, computer experience differed significantly between the two groups (less computer experience in group 2) and the correlation between computer experience and enclosedness was close to significant ($r = -0.30$, $p < 0.067$). The age and computer experience variables might thus to some extent have contributed to explaining the difference in enclosedness found between the two groups. These results, taken together, again suggest, but in a somewhat different way, that the experience of the VR model gave a fairly good idea of how the real building would be experienced, this time by a different group who had not been influenced by having experienced the VR model.

Our results in the first study are informative with regard to how the usability of VR models in the later stages of the architectural planning process could be improved without investing resources to perfect the properties of the VR model on all fronts. However, we note that the correlations discussed below were only moderate and in need of replication. The first study showed that two of the background variables investigated were associated with how the respondents experienced the VR model. The most influential of these was computer experience and the other was the level of education. Respondents with more computer experience, for example, reported greater difficulty in making use of the external environment compared with the respondents with less computer experience. One interpretation of these findings is that the experienced respondents were better able to see the "tricks" of the programmer and therefore found it more difficult to perceive the model as intended by the programmer. To some extent the results were similar for computer experience and level of education. Respondents with a higher level of education and more computer experience, for example, had a greater tendency to report becoming bored with the VR model. A conclusion to be drawn from these results is that when deciding how much development resources to spend on the VR model in order to achieve a model that is experienced well, it is relevant to pay attention to the amount of computer experience and possibly also the education of the respondents.

When discussing the ability to use VR models for certain tasks it is often said that presence is important for performance. There are several factors that have been identified as contributing to the total experience of presence [16]. Some of these factors are: the number of senses used when experiencing the model, the ability to manoeuvre in the model, and how immersive the presentation of the model is. It seems clear that experiencing presence is a question of degree.

In the present study, several of these factors were not at hand. The respondents did not have the opportunity to control the model directly, although in the present results no correlation was found between understanding the model (exterior or interior) and wanting to control the model themselves. Furthermore, the model was shown on a powerwall with 3D-glasses but the shows were not immersive. The model did not contain any sound or influence any other sense apart from vision. In spite of the discrepancies from a high degree of presence, the respondents reported that they had gained a fairly good understanding of their future work environment. A reasonable conclusion is that fully experienced presence is not necessary, or at least it is not as important, for all types of tasks VR models can be used for in the building process. Put alternatively, if VR models are defined as models providing a full sense of presence, full-scale VR models are presumably not needed at all stages or for all tasks in the building process.

It is also of interest to consider how the VR experience may have affected the experience of the real building. Although, as elaborated on below, our design does not allow any in-depth analysis in this respect, it is still of interest to note that only two SMB factors differed between the results in 2003 for the group who had experienced the VR model and the group who had not. These were the enclosedness factor and the affection factor. In both cases, the values for the group that had not experienced the VR model were higher but it was only substantially so for the enclosedness factor (more than one scale unit). However, since the design did not allow for random assignment to the groups, it is not possible to claim that it was the VR experience that lay behind the differences between the groups. Compatible with this, the correlations between age and computer experience with enclosedness may explain partly or fully the difference between the groups with regard to this variable. A tentative conclusion is that the experience of a VR model did not to any large degree influence the experience 2 years later of the real building that was depicted in the model. It remains for future, better controlled, research to check for other differences in background variables between the groups, which may explain the differences found.

Due to different methodological limitations, this study should be regarded as a pilot study that has provided hypotheses in connection with different research questions for future research. For example, what properties of a VR model are useful at different stages in the building process? To what extent do individuals vary with regard to the extent to which their VR experience corresponds to their experience of the resulting real building? To what extent is fully experienced presence necessary for a VR model to be a useful aid in different stages in the building process? To what extent does the experience of a VR model of a building influence the future perception of, and ability to orientate oneself in, the completed real building?

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