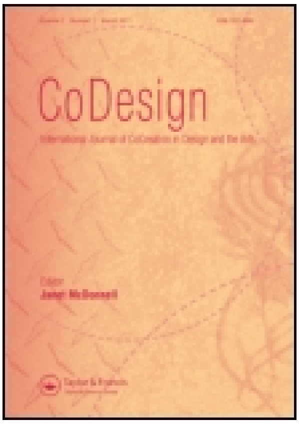

CoDesign: International Journal of CoCreation in Design and the Arts
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ncdn20

Using interactive model simulations in co-design: An experiment in urban design

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To cite this article: Marc Steen , Jeroen Arendsen , Anita Cremers , Arnoud De Jong , Jacomien De Jong & Nicole De Koning (2013): Using interactive model simulations in co-design: An experiment in urban design, CoDesign: International Journal of CoCreation in Design and the Arts, 9:1, 2-16

To link to this article: http://dx.doi.org/10.1080/15710882.2012.755549

CoDesign, 2013
Vol. 9, No. 1, 2–16, http://dx.doi.org/10.1080/15710882.2012.755549

Using interactive model simulations in co-design: An experiment in urban design

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(*Received 7 November 2011; final version received 26 November 2012*)

This paper presents an experiment in which people performed a co-design task in urban design, using a multi-user touch table application with or without interactive model simulations. We hypothesised that using the interactive model simulations would improve communication and co-operation between co-design participants, would help participants to develop shared understanding and would positively affect the co-design process and its outcomes. However, our experiment (involving 60 people in 20 co-design sessions) only partly confirmed these hypotheses. People positively evaluated the interactive model simulation tools (an interactive map of an urban area, interactive models for traffic, sound, sight and safety, and 'tangibles'), and these tools promoted communication and co-operation, and the exploration of design solutions. However, people's experiences of social cohesion and their satisfaction with their own contribution to the co-design process were better *without* these tools, possibly because using these tools drew people's attention towards these interactive model simulations and away from the dynamics between the participants. We therefore advocate using such tools selectively, for example, early on in a co-design process, to improve shared understanding of the contents of the problem, rather than later on, when people need to focus on their fellow participants and on the processes of communication and co-operation.

Keywords: collaborative design; experiment; shared understanding; satisfaction; interactive model; simulation; urban design

1. Introduction

In recent years, the Municipality of The Hague (The Netherlands) has experimented with a co-design approach to urban design to allow citizen participation (Den Haag 2010). Rather than having a group of civil servants and technical experts make plans and present these to citizens when the plans are almost finalised, they involve citizens during the process, through a series of meetings and workshops. Although this co-design process takes place within the context of the Structural Plan of the Municipality, their approach does leave a relatively large amount of room within which to manoeuvre. The results of the co-design approach in The Hague have been positive so far. Both civil servants and citizens appreciate the process of co-operating actively and creatively, and the resulting plans are said to be of higher quality and can be implemented more easily compared with the

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traditional route, because they are recognised and supported by both groups: civil servants and citizens.

In co-design, participants with different backgrounds, perspectives, roles and interests meet each other and bring their knowledge and ideas together to jointly explore and define the problem and explore and develop possible solutions (Steen 2012, 2013; Steen, Buijs, and Williams 2013). Co-design stimulates 'collective creativity' during the various phases of a design process (Sanders and Stappers 2008). Co-design has proven to offer many benefits, ranging from benefits for idea generation, such as diversity of ideas, through benefits for the participating organisations, such as increased co-operation, to benefits for the longer term, such as improved satisfaction of users (Steen, Manschot, and De Koning 2011). Urban design is an interesting candidate for co-design, because it is highly collaborative and involves diverse participants and stakeholders. In addition, the stakes in urban design are high; lots of time and money are involved and decisions made have long-term effects. It is therefore critical that participants communicate and co-operate effectively and creatively. However, the large diversity of perspectives and levels of (technical) expertise of the participants – civil servants, citizens, but also (technical) experts in various areas – may hinder this co-operation.

In many design processes – and urban design is no exception – the list of requirements that are articulated by the diverse stakeholders is long and diverse. Moreover, each participant will tend to focus on those requirements that are most relevant for them. Each will want to explain why their issues are important, how they should be taken into account in the design and why certain design solutions are better than others. For example, a civil servant wants to promote local businesses, a police policy official wants to ensure public safety, and a civilian representative strives for local shops and recreation options. Furthermore, technical experts will typically offer advanced knowledge and models, in order to evaluate different design solutions in terms of, for example, traffic volumes, noise levels or public safety. This expertise is essential in decision making, since it offers the preconditions for options, for example in terms of legislation, as well as a 'reality check' for all stakeholders on the effects of certain decisions.

From a co-design perspective, it would be good if all stakeholders (in particular citizens) were able to participate in the discussion of requirements and in contributing their own experiences, ideas and perspectives to the process of developing solutions. In urban planning, visualisations of the current situation and possible future ones may be of great help. However, using simple paper drawings or cardboard models may not suffice in a discussion of advanced technical issues with experts. Participants would be better supported by a shared, easy-to-use tool, in the form of visualisations of solution alternatives and associated interactive model simulations for jointly exploring the problem and jointly developing solutions. With such a tool, participants would be able to express and discuss their perspectives on the problem and on possible solutions, thereby creating a common experience of realistic design alternatives. For example, a police representative, using a safety model visualisation, could show that a certain design alternative will create one very unsafe area, while a citizen representative, using a noise model visualisation, could point out that another design alternative creates too much noise in a residential area.

When following a co-design approach with appropriate support tools (such as interactive model simulations), diversity in perspective and expertise can be viewed as an advantage and can actually turn into a benefit. However, little is known yet of the effects of using such interactive model simulations on the process of co-design. The goal of this paper is to further our understanding of the ways in which interactive model simulations and visualisations can support co-design. Although our study focuses on urban design, the findings are also relevant to other domains where multiple stakeholders discuss a design problem.

2. Co-design with interactive tools

Our view on co-design seeks to combine a cognitivist perspective, which starts from the notion that participants have different mental models and that they need to develop shared understanding (Kleinsmann, Valkenburg, and Buijs 2007; Kleinsmann and Valkenburg 2008), and a social perspective, which starts from the notion that co-design is inherently a social process, in which participants communicate, co-operate and negotiate with each other (Bucciarelli 1994; Ehn 1990; Greenbaum and Kyng 1991).

From a cognitivist perspective, developing shared understanding – that is, a similarity in co-design participants' perceptions of both the design content and the design process (Kleinsmann and Valkenburg 2008; cf. Kleinsmann 2006, Kleinsmann, Valkenburg, and Buijs 2007) – promotes the formation of shared mental models or team mental models (Badke-Schaub et al. 2007). Shared mental models are especially important for tasks that require effective communication and co-operation between diverse people. The people involved need to develop a shared understanding of how the team works, of the process of working together, of different project-team members' competences, of the context of the project and of the contents of the task (Badke-Schaub et al. 2007). Note that increased shared understanding does not necessarily imply that participants have the same ideas or that they agree; rather, it means that they better understand each other's perspectives and ideas. They may still very well 'agree to disagree', for example. Indeed, too much similarity in mental models may introduce the risks of oversimplification and groupthink; that is, the disadvantageous effects of too much uniformity (Boos 2007).

From a social perspective, satisfaction of participants with the co-design *process*, with their own *contribution* to this process and with the *outcome* of the co-design process are stressed (Post, Huis in 't Veld, and Van den Boogaard 2008). Since co-design involves the blend of different participants' perspectives and ideas, it is possible that one participant feels less satisfied with the outcome, for example, because her preferences were given less weight then other people's ideas. However, she can still feel satisfied with the process of co-design, for example, when she understands other participants' ideas and can appreciates the process of decision making. One can feel less happy about the outcomes and, at the same time, evaluate the process positively, for example because one understands the negotiation process and appreciates other participants' interests, and because one feels satisfied about one's own contribution to the process. If participants are satisfied with the process, own contributions and outcome, this strengthens *social cohesion* within a team (Post, Huis in 't Veld, and Van den Boogaard 2008). However, the sharing of too much knowledge or discussing too many design alternatives can lead to *information processing* overload (Post, Huis in 't Veld, and Van den Boogaard 2008). Participants' satisfaction is especially important when participants act as representatives. If, for example, the police representative and the citizen representative are satisfied, their support for the project can be shared with the people they represent, which will positively influence the support for the project.

Co-design enables people to more thoroughly examine the design space by generating more and diverse design alternatives, and to jointly develop better quality design solutions [cf. *CoDesign* Special Issues: Design Participation (− s), 4 (1–2) in 2008 and Participatory Engagement in Design, 8 (2–3) in 2012]. Furthermore, several studies on using interactive table-top displays for collaboration have been carried out, which suggest that such tools can promote co-operation and shared understanding among participants. Scott, Grant, and

Mandryk (2003), for example, discussed the design of systems with a table-top display for collaboration. Such a system should facilitate natural interpersonal interaction, enable participants to use physical objects and to access shared physical and digital objects, and facilitate transitions during the process of co-design, for example, between personal and group work, and between table-top collaboration and external work. Vosinakis et al. (2008) discussed the potential of virtual environments for collaborative design and proposed guidelines to support diverse forms of action and interaction: instrumental action (to control and manipulate physical artefacts), communicative action (to develop shared understanding), discursive action (to establish conditions for collaborative action) and strategic action (to influence participants' behaviour). Finally, Wang and Chen (2009) conducted an experiment to study the potential of augmented reality technology (the addition of virtual entities to the real world) in urban design. They compared the performance and effectiveness of using traditional wood blocks versus using augmented reality and found that the latter offered significant potential for urban design. In conclusion, table-top displays and virtual entities seem to be able to contribute positively to co-design. However, little is currently known about the benefits of interactive simulations to co-design.

Our research question is therefore: Do interactive model simulations support co-design? Our hypothesis is that using interactive model simulations can help co-design participants to produce more and better quality design solutions, and to develop shared understanding, for example, by making specialised knowledge readily available or by improving information sharing communication and co-operation. We expect that this would have positive effects on participants' satisfaction and social cohesion within the group and would diminish possible detrimental effects, such as groupthink and information overload.

3. Experimental design and procedure

In this section, we present and discuss the experimental design, the participants and the urban design task that they worked on, the prototype and its features in the different conditions of the experiment, the procedure, the measures and our hypotheses.

3.1. Experimental design

We conducted an experiment in which groups of three people engaged in role-playing to collectively work on an urban design task supported by a surface table. The task consisted of placing four new buildings (in the form of wooden tangibles) in an existing neighbourhood (represented as a map on the surface table). The participants were each given different roles – a civil servant of urban planning, a citizen representative and a police policy official – and role descriptions with their different goals and interests. The experimental design had two conditions: Condition NI (non-interactive), in which the participants were provided with a non-interactive multi-user application that presented a map of the situation on which the participants could try out different design ideas; and Condition I (interactive), in which the application was an interactive multi-user, multi-touch application, on which the participants could try out different design ideas, the effects of which – on traffic, sound, sight and safety – were simulated and visualised in real time. In both conditions, a researcher in the role of 'expert' was available for answering technical questions about traffic, noise, sight and safety.

All groups participated in both Conditions NI and I (within-subjects design), using two different map layouts (to avoid learning effects). To study the effects of the order of conditions and map layout, groups were randomly assigned to one of the following four experimental sequences: (1) first NI and Map 1, then I and Map 2; (2) first NI and Map 2, then I and Map 1; (3) first I and Map 1, then NI and Map 2; or (4) first I and Map 2, then NI and Map 1.

3.2.2. Participants and task

In total, 60 people were recruited to participate (from a database of people who are willing to participate in such experiments). They were divided into 20 groups of three people (31 men and 29 women; ages ranged from 18 to 62 years, with an average of 26.5 years). The groups were randomly attributed to one of the four sequences (five groups for each sequence). Furthermore, participants were randomly assigned to different roles (civil servant, police policy, citizen representative). After the experiment, they received travel expenses and a remuneration of 20 euros each.

The participants received general information on the context of their urban design task (Box 1) and role-specific information (Box 2, for one example). The latter included preferences for each specific role, with a motto (civil servant: 'Green skyline'; police: 'Safety first'; citizen representative: 'Village of the past'). Participants also received a drawing of a solution that would meet this specific role's preferences and priorities (incompatible or only partly compatible with the solutions of the other roles). This information was not shared beforehand with the other group members, but could be brought into the discussion during role-playing.

3.3. Prototype

A prototype application was developed for an interactive surface table (Figure 1). The table screen presented a map of the relevant neighbourhood as a grid of squares, with features such as current buildings, roads and a park. The four new buildings that the

Box 1. Information for all participants on the urban design task.

Background: The neighbourhood Square in the municipality of Circle has recently had a large increase in residents. The neighbourhood facilities, however, are rather restricted and dispersed. That is why the city has made some plans to increase the level of facilities. They want to implement the 'American model', which entails centralised facilities as much as possible. They have already tried to centralise the medical facilities in and around the hospital. Now they want to continue with other facilities: schools, shopping, entertainment and industry.
Current situation: The neighbourhood Square consists of four areas, divided by roads, one wide road with a lot of traffic and one quiet, narrow road: two residential areas with only low buildings, one housing mainly families with young children and one with also elderly people; one area with a tall hospital building, other buildings with medical services, and elaborate parking facilities; and one area with a large city park, with trees, walking paths, a lake, a children's farm and parking facilities.
Plans: In the next years, the municipality of Circle wants to build four central facilities: schools, shops, entertainment and factories. Building locations have already been selected and cannot be changed. The question is what the exact location of the facilities will be and whether they will be low or tall buildings. The locations that will remain empty will become a park. The municipality, residents and the police have different ideas, but they will have to come to an agreement.
The buildings: The assignment is to find suitable locations for four buildings: *a school building* that houses an elementary and a high school; *a shopping centre*, with a supermarket, and other shops, such as chemist, clothing shops and book shops; *an entertainment centre*, including a large café for lunch and dinner, and dancing with night-time opening, a theatre and a cinema; and *an industrial facility*, with a bread factory and an office building.

Box 2. Role-specific information for the civil servant

Civil servant: 'Green skyline'
The municipality believes that centralisation will result in a more modern 'look and feel' for Circle, which will enhance economic activity. This 'look and feel' should also be physically apparent: the more tall buildings the better. They also want to boost cultural life, but not at the expense of greenery. The neighbourhood Square wants to become known as the 'Green skyline'.
Preferences in order of priority (1 = highest)

(1) Factories: Factories will stimulate economic activity. They will form a 'High-Tech Park', with a lot of high-rise. The location is less important. Near the hospital seems to be the best location, since it offers convenient transport routes for materials and products, both during the day and at night.
(2) Shops: The shops should form a 'Shopping mall', inspired by the American example. This means a location that can be easily reached, also from other municipalities, with ample parking facilities. Certainly not in a residential area.
(3) Recreation: 'Broadway in the neighbourhood' is the motto. A central area where locals, young and old, meet each other, where they can visit bars, restaurants and cinema, there is something for everyone. It does not require driving there. The destination is apparent, because of the tall tower. In the evening the streets will have a lively atmosphere. Broadway should not be close to the hospital. That is too far away and there is no nice atmosphere.
(4) Schools: The local youth should get used to the 'Green skyline' as early as possible. That is why the schools should be located in the park (the Campus). An architect specialising in co-design has already made plans for the desired tall buildings, including roof gardens. The existing petting zoo is also nearby.

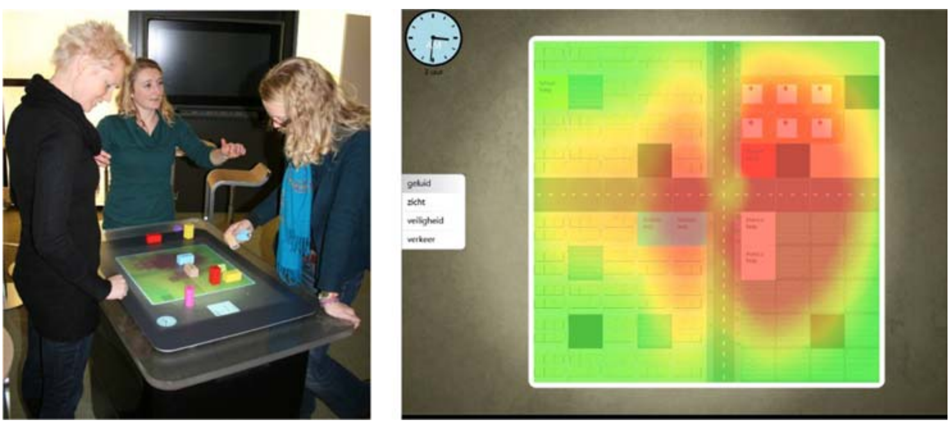

Figure 1. Participants in the experiment, around the surface table (left). The coloured blocks are 'tangibles' and represent new buildings. The pink cylinder operates the clock. The interactive simulation (Condition I) (right) offers: visualisation in red, yellow and green colour 'heat maps', dark grey squares for empty slots for buildings, the menu for the four simulations (sound, *geluid*; sight, *zicht*; safety, *veiligheid*; traffic, *verkeer*) and a clock to manipulate the time for one of the simulations. The non-interactive condition (Condition NI) has no simulations, no menu and no clock.

participants needed to place on the map were represented by wooden blocks, called 'tangibles'. There were four kinds of buildings – a school, a shopping centre, an entertainment centre and an industrial facility – with different colours. Furthermore, there were two versions of each kind of building: a low building that occupied two squares and a high building that occupied one square.

On the map were 11 black-coloured squares that indicated empty, available building locations; there were one-square locations that would accommodate a high building and two-square locations that would accommodate a low building. The distribution of squares was designed in such a manner that it was not possible to place only low buildings, but to have enough possibilities to create discussion among the three role players. Thus, if all buildings were placed, the number of spots occupied varied between four and seven, leaving seven to four spots open. Two different maps were available, which differed only in the layout of the neighbourhood.

In Condition I, several additional functionalities were made available. When a building was placed on the table, it was recognised by the application through a visual marker stuck to the bottom of the block. There was a menu that presented four simulations for traffic, sound, sight and safety. Once one of these simulations was selected, a visualisation was presented on the map surrounding the buildings, showing the effects of the buildings in the form of 'heat maps': green indicated small or positive effects, yellow intermediate effects, and red large or negative effects. Furthermore, an analogue clock was presented in Condition I, which participants could manipulate in order to simulate and visualise effects on different times of the day. Using the clock, one could see, for example, increasing traffic during rush hours and decreasing safety at night in the park.

3.4. Procedure

The experiment took between 60 and 90 minutes for each team. Each team first received an introduction with the goal of the experiment and gave consent. Then, they were given a pre-test questionnaire. Next, they read the background and role-specific information. Then, they were invited to gather around the table, each of the three participants and the test leader on one side, and the test leader explained the role-playing and the assignment. She stressed that they needed to try to develop a solution that would work best for all of them, which means that everybody should try to represent their own goal and interests, and also to be prepared to compromise for the collective goal. One session was planned to take a maximum of 15 minutes, but they could stop whenever they were ready.

Furthermore, the test leader explained her own role as an expert on the four technical topics – noise, view, traffic and safety – and pointed out that she was available for questions, but would not offer information spontaneously. She encouraged the participants to use the blocks ('tangibles') during the session. The end result of their task was a situation where all four buildings were placed at available locations. After the first session, the participants were invited to fill in a questionnaire (with questions about their satisfaction and shared understanding), while the test leader set up the second session, with another condition and another map layout. After that, the participants gathered around the table again and the test leader explained the changed functionality of the application. Next, the participants conducted a second session and then filled in the same questionnaire (with questions about satisfaction and shared understanding) for the second time. In addition, they were invited to answer a final questionnaire (with questions about their preference for Condition NI or Condition I and their evaluations of the interactive elements).

3.5. Measures

Before, during and at the end of the experiment various objective and subjective measurements were taken. Pre-test, the Ten-Item Personality Inventory (TIPI) questionnaire (Gosling, Rentfrow, and Swann 2003) was used to assess participants' character traits ('the big five') (10 items, seven-point Likert scales), which could possibly affect their role-playing.

Questionnaires were used after the first and second sessions, which contained statements (using seven-point Likert scales) concerning participants' experiences of the presence (or absence) of enablers of shared understanding (nine items) (Box 3). These enablers are based on a study by Kleinsmann and Valkenburg (2008, 380), in which they identified key factors that affect shared understanding, which they categorised into three main groups, on different levels: actor, project and organisation. For our purposes, we selected the most relevant items from their overview (see remarks in Box 3). Furthermore, questionnaire items were used to evaluate participants' *satisfaction* with the group *process* (four items), with their individual *contribution* to the group process (three items) and with the *outcome* of the process (four items) (Box 4). In addition, questionnaire items were used to assess participants' experiences of *information processing* (four items) and *social cohesion* (three items) (Post, Huis in 't Veld, and Van den Boogaard 2008) (Box 5).

Furthermore, we used a questionnaire after the second session, which contained questions concerning people's preference for Condition NI or Condition I (using seven-point Likert scales), their evaluations of the interactive elements (surface table, tangibles, the four interactive models and the clock), and open questions about suggestions for improvements and other remarks.

During the sessions, the test leader made notes of the number of questions that the groups of participants asked her, in her role of expert (co-design *process*). Furthermore, two aspects of the usage of the *surface table* were logged for each group of participants, in both conditions: the number of manipulations (co-design *process*) and the number of design alternatives (co-design *outcome*). A certain situation was assumed to be a design alternative if no block manipulation had taken place in 20 or more seconds. These measures were used as an indication of the quality of the design process; the more exploration of the design space, the better.

Box 3. Questionnaire items for participants' experiences of enablers of shared understanding.

In this session …

1. … I was able to convey my position/perspective (cf. 'The ability of the actor to make a transition of knowledge', actor level)
2. … I was able to empathise with the other participants' interests (cf. 'The empathy of the actor about the interest of a task', actor level)
3. … I had a clear view on the design task (cf. 'The view of the actor on the design task', actor level)
4. … Participants used the same language (cf. 'The equality of the language used between the actors', actor level)
5. … I had a clear view on the process (cf. 'The view of an actor on the process to follow', actor level)
6. … I had a clear view on what was important for the other participants (cf. 'The prospect of the actor on the task of the other actors', actor level)
7. … we were able to efficiently process the available information (cf. 'The efficiency of information processing', project level)
8. … we were able to evaluate the quality of each design/option (cf. 'The controllability of product quality', project level)
9. … specialised knowledge was available (cf. 'The availability of specialised knowledge within the company', organisation level)

References are to Kleinsmann and Valkenburg (2008, 380).

Box 4. Questionnaire items for participants' experiences of satisfaction with the process, with their own contribution and with the outcome.

I am satisfied . . .
(Process)

1. . . . with the way in which the group has reached a decision
2. . . . with the discussion in the group
3. . . . with the way in which we have exchanged information
4. . . . with the way in which we have developed ideas

(Own contribution)

5. . . . about the extent to which I was able to reach my interests and goals as a stakeholder
6. . . . about the extent to which I was involved in the design process
7. . . . about the extent to which I was able to exert influence

(Outcome)

8. . . . about the completeness of the design (the extent to which all requirements were met)
9. . . . about the correctness of the design (does it match the requirements?)
10. . . . about the goal-orientation of the design (does it match the goal?)
11. . . . about the design in general

Box 5. Questionnaire items for participants' experiences of information processing and of social cohesion.

(Information processing)

1. We have shared the necessary information well.
2. We were able to integrate the necessary information well.
3. Everybody's individual contributions have influenced the design process.
4. Because all team members contributed a piece of the puzzle we could finish the job.

(Social cohesion)

1. I found the other team members helpful.
2. I found the other team members trustworthy.
3. I found the other team members easy-going.

3.6. Hypotheses

We hypothesised that Condition I has positive effects on the co-design process and on the co-design outcomes, compared to Condition NI. More specifically, we articulated the following hypotheses:

- Hypothesis 1: Participants prefer Condition I over Condition NI, and positively evaluate the interactive model simulations and support elements (measured as participants' evaluations of surface table, tangibles, interactive models and clock).
- Hypothesis 2: Participants in Condition I experience more *shared understanding* (measured as participants' experiences of the presence of enablers of shared understanding, see Box 3), higher *satisfaction* (measured as participants' satisfaction with the process, their own contribution and the outcome; see Box 4),

and better information processing and social cohesion (see Box 5), than in Condition NI.

- Hypothesis 3: Participants in Condition I use more *manipulations* and produce *more solution alternatives* (measured automatically by the system), and ask *fewer questions of the expert* (because the interactive models provide 'answers', assessed through observation, as measures for exploration), than in Condition NI.

4. Results

The results of the experiment are presented below, starting with a general evaluation, followed by the co-design process and the outcomes. But first, we discuss the reliability of the measured constructs and the possible influence of participants' personal characteristics.

4.1. Reliability of constructs

The constructs of *satisfaction* and *shared understanding* were measured using multiple items in the questionnaire, ranging from three to nine items. We found that in each case the items were reliable measurements of the constructs.[1] For most of the constructs this was expected given their earlier performance, reported by Post, Huis in 't Veld, and Van den Boogaard (2008). The measures for participants' experiences of the enablers of shared understanding, which were adapted from Kleinsmann and Valkenburg (2008), were also found to be reliable.[2]

4.2. Participants

To study whether participants' satisfaction or their level of shared understanding depends on their own personality, we measured their 'big five' personality characteristics using the TIPI (Gosling, Rentfrow, and Swann 2003). Correlations were then checked between these personality characteristics and the other measurements, in both conditions. In all but two instances no significant correlations were found. The two significant correlations found were the following: (1) for both the NI and I conditions, *conscientiousness* was positively correlated with the experience of the presence of enablers for shared understanding;[3] and (2) a high *openness to experience* contributed to high scores on *shared understanding* in Condition NI,[4] but not in Condition I. The first correlation, the only one that was stable across conditions, was taken into account in the further analysis of the results. Otherwise, participants' personal characteristics were not considered any further.

4.3. Interactive simulations

After participating in two sessions, experiencing both conditions, participants were asked to indicate their preference for one of the conditions and to grade the support elements. The support elements *surface table* and *tangibles* were present in both conditions, whereas the four *models* and the *clock* were present in Condition I only. As expected, most participants, 47 out of 60, reported a strong to mild preference for Condition I. However, eight participants reported a (mild) preference for Condition NI, and five were neutral.

Furthermore and as expected, the participants appreciated the support elements, which they rated with '7' or higher on a 10-point grading scale (see Table I). However, participants did not grade the components equally highly. Post-hoc analyses showed that,

Table I. Participants' evaluations of surface table, tangibles, interactive models (safety, sound, traffic, sight) and clock, as grades from 1 (lowest) to 10 (highest).

	Mean	SD
Surface table	8.35	0.908
Tangibles	7.93	1.011
Model safety	7.26	1.493
Model sound	7.09	1.368
Model traffic	6.86	1.220
Model sight	6.64	1.683
Models (average)	6.96	1.441
Clock	7.09	1.437

on average, the *surface table* and the *tangibles* were appreciated more than the *clock* and the *models*. Neither condition order nor map layout had any effect on these results.

4.4. Shared understanding

No main effects were found of condition or condition order on participants' experience of *presence of enablers for shared understanding*, but we did find a significant interaction between condition and condition order, with Condition NI scoring higher in the I–NI order than in the NI–I order.[5] Differences in *presence of enablers for shared understanding* were tested with *conscientiousness* added as a covariate because the two measures correlated (see Section 4.2).

Presence of enablers was equal in the two conditions. Interestingly and understandably, people with higher *conscientiousness*, that is, people who tend towards careful ways of working, appreciated more the presence of enablers for shared understanding.

4.5. Satisfaction

No differences between Conditions NI and I in participants' experiences of satisfaction with the group process, or between subjects using different condition orders or map layouts were found.[6] However, participants' reported satisfaction with their own contribution to the process was significantly higher in Condition NI [mean (M) = 18.1, standard deviation (SD) = 0.36] than in Condition I ($M = 17.0$, SD = 0.44), contrary to our expectation, and also higher with condition order I–NI ($M = 18.3$, SD = 0.48) than with condition order NI–I ($M = 16.8$, SD = 0.48).[7]

Participants reported equal satisfaction with the *outcomes* of the co-design process for Conditions I and NI. However, we also found an effect of condition order, with satisfaction with the outcomes being significantly higher with I–NI ($M = 23.1$, SD = 0.66) than with NI–I ($M = 20.9$, SD = 0.66).[8]

Participants' experiences of *information processing* were equal in both conditions, but were higher with condition order I–NI ($M = 24.1$, SD = 0.59) than with condition order NI–I ($M = 21.9$, SD = 0.60), and again there was a significant interaction between condition and condition order, with condition NI scoring higher in the I–NI order than in the NI–I order.[9] Participants' experiences of *social cohesion* were significantly higher in Condition NI ($M = 18.7$, SD = 0.29) than in Condition I ($M = 18.0$, SD = 0.32), and also higher with condition order I–NI ($M = 18.9$, SD = 0.37) than with condition order NI–I ($M = 17.8$, SD = 0.38).[10]

Social cohesion was unequal in the two conditions, while information processing was equal. Contrary to our hypothesis, social cohesion was lower for Condition I. Furthermore, there was a condition order effect, in that I–NI (compared to NI–I) resulted in better information processing and social cohesion, and an interaction effect, in that NI resulted in better information processing and social cohesion in I–NI order (compared to NI–I order).

4.6. Exploration

Participants carried out significantly more manipulations of the 'tangibles' in Condition I ($M = 98.8$, SD $= 42.2$) than in Condition NI ($M = 68.1$, SD $= 35.5$) and this was not affected by condition order.[11] In addition, they produced more solution alternatives in Condition I ($M = 14.7$, SD $= 2.98$) than in Condition NI ($M = 12.1$, SD $= 5.08$) and this was also unaffected by condition order.[12] Furthermore, based on observation, participants in Condition I asked fewer questions of the expert than in Condition NI.

5. Discussion

In line with Hypothesis 1, we found that participants preferred using the interactive table over the non-interactive table, and that they positively evaluated the surface table, the tangibles and the interactive model simulations. However, the models were graded lower than the surface table and the tangibles.

Hypothesis 2 – that using interactive model simulations would promote shared understanding and improve satisfaction – was *not* confirmed. On the contrary, several participants' experiences of social cohesion and their satisfaction with their own contribution to the co-design process were better without the interactive models (Condition NI) than with them (Condition I). In addition, there were some order effects: people who first used the interactive table (I) and then the non-interactive table (NI) were more positive about the non-interactive table than people who first used the non-interactive table (NI) and then the interactive table (I), also in terms of their satisfaction with the *outcomes* of the co-design process.[13]

There are several ways to interpret these effects. One possible explanation is that using the interactive model simulations can draw people's attention towards the table itself and away from the people around the table, which is likely to negatively affect people's experiences of social cohesion and their satisfaction with their contribution to the co-design process. Focusing on what happens *on the table* can hinder people in focusing on the social process *around the table*. Another explanation for this order effect would be the following. If people first use the interactive table (I) and then the non-interactive table (NI), they are able to play with the models, which helps them to understand other participants' roles and interests, and ways to negotiate and combine these roles and interests productively. In that case, using the interactive table offers a playful introduction to the social dynamics that are inherent to co-design. If people then do a second session, with the non-interactive table, they can evaluate this second session more positively (compared to the first session, with the interactive table) because they now understand and enjoy the social dynamics better. First using the interactive table functions then as a warming-up exercise for the second session (without the interactive models). A similar explanation focuses on the contents of the interactive models: if people first use the interactive table, they can learn about the contents of the models, and how these models relate to participants' roles and interests, so that they can perform better in the second session (without the interactive models) because they now understand the contents of the design task better.

We would like to remark that using such interactive models can bring the risk that people start to treat the interactive models as infallible. When an expert provides expert knowledge, the participants can ask her to explain that knowledge, for example, by providing background information or by explicating implicit assumptions. However, they cannot ask questions of the interactive model. They will either believe or not believe the model at face value. This may also have contributed to participants' lower satisfaction with their own contribution to the co-design process. To a certain extent, using these models may make technical experts redundant. However, technical expertise is still needed for more detailed analyses after certain high-level solutions have been chosen.

We would also like to mention that the participants were not professionals and the urban design task was rather artificial. We randomly assigned the roles to the participants. One way to increase realism is to ask the participants to choose a role that that they believe would fit their own character or attitude (civil servant, police or citizen representative). Another way, of course, would be to conduct the experiment in a more realistic context: with professionals and with a realistic urban design task.

Moreover, we found that people used more manipulations, produced more solution alternatives and asked fewer questions of the expert in the condition with the interactive models. This is in line with Hypothesis 3, and illustrates the added value of using interactive model simulations for the co-design process. However, a possible drawback of using more manipulations, producing more solution alternatives and asking fewer questions could be that participants communicate and co-operate less with each other. We speculate that, when participants were asked to report on their experiences (as assessed with the questionnaire items on Shared understanding, Social cohesion, Information processing and Satisfaction) they might have focused their reporting more on the social aspects of the situation, their experiences of interacting with each other; and less on the contents of the situation, the manipulations and the exploration of solution alternatives. This could explain the lower evaluation of the interactive condition (compared to the non-interactive condition).

Finally, we would like to remark that our experiment combined cognitivist and social perspectives by evaluating phenomena that combine cognitive and social aspects of co-design: participants' experiences of the enablers of shared understanding; their satisfaction with the group process, with their individual contribution, and with the outcomes of the process; and their experiences of information processing and social cohesion.

6. Conclusions

We hypothesised that using interactive model simulations would improve communication and co-operation between co-design participants, and that this would promote shared understanding and satisfaction, and would positively affect the co-design process and its outcomes. We organised experiments in which people participated in an urban design task, under two conditions: using an interactive table with interactive model simulations, and using a non-interactive table.

From our experiments we can conclude that people appreciated the use of interactive model simulations (H1) and that these promoted the exploration and development of alternative design solutions (H3). However, using these simulations can also have negative effects on participants' experiences of social cohesion and their satisfaction with their own contribution to the co-design process (H2).

Despite the small number of experiments and the limited observations, we would like to speculate that interactive model simulations can help co-design participants. For example, these tools can be helpful at the start of a co-design session or of a co-design process, as a way to help participants to get to know the other participants, and their roles, perspectives and interests, and to better understand the social dynamics as well as the contents of problem. We speculate that it would be better to use the interactive simulations modestly later in the session or later in the process, in order to allow the participants to then focus on communication and co-operation with each other, and on carefully balancing and negotiating their perspectives and interests, in order to jointly develop solutions that can be supported by all participants.

In closing, we would like to suggest future research into several areas. It would be interesting to further study possible extensions of the interactive model simulations, such as: using multi-modal interaction, for example, by producing sounds to present the effects of the sound model (rather than presenting green, yellow and red colours); using tools to monitor group dynamics, for example, monitoring which participant is speaking and for how long (Friedland and Van Leeuwen 2010); or using tools that allow citizens to create and upload video clips online, in which they can express their experiences and needs, so that they can be viewed and taken into account during a co-design session. It would also be interesting to study the benefits of using interactive simulations in realistic design situations with professional participants and with realistic urban design tasks, for instance as part of a citizen participation project. We would like to find out, for example, whether the 'novelty effect' – the initial focus on technology, rather than on people – diminishes in realistic settings and with repeated use.

Acknowledgements

The authors would like to thank the anonymous reviewers for their thoughtful reviews and helpful comments.

Notes

1. Cronbach's alpha ranging between 0.78 and 0.9.
2. Cronbach's alpha of 0.87.
3. NI: Pearson correlation 0.347, $p = 0.007$; I: Pearson correlation 0.342, $p = 0.008$.
4. Pearson correlation 0.338, $p = 0.008$.
5. Repeated measurement: condition (55, 1), $F = 0.54$, $p = 0.818$, n.s.; condition order (55, 1), $F = 3.05$, $p = 0.086$, n.s.; condition map (55, 1), $F = 3.99$, $p = 0.051$, n.s.; conscientiousness (55, 1), $F = 4.93$, $p = 0.031$; condition*condition order (55, 1), $F = 6.11$, $p = 0.017$.
6. Repeated measurement: condition (56, 1), $F = 1.51$, $p = 0.224$, n.s.; condition order (56, 1), $F = 2.60$, $p = 0.113$, n.s.; condition map (56, 1), $F = 1.70$, $p = 0.198$, n.s.; condition*condition order (56, 1), $F = 3.15$, $p = 0.081$, n.s.).
7. Repeated measurement: condition (56, 1), $F = 5.93$, $p = 0.018$; condition order (56, 1), $F = 4.77$, $p = 0.033$; condition map (56, 1), $F = 1.54$, $p = 0.220$, n.s.; condition*condition order (56, 1), $F = 0.83$, $p = 0.365$, n.s.
8. Repeated measurement: condition (56, 1), $F = 1.68$, $p = 0.178$, n.s.; condition order (56, 1), $F = 5.42$, $p = 0.024$; condition map (56, 1), $F = 1.48$, $p = 0.228$, n.s.; condition*condition order (56, 1), $F = 2.20$, $p = 0.143$, n.s.
9. Repeated measurement: condition (56, 1), $F = 0.37$, $p = 0.547$, n.s.; condition order (56, 1), $F = 6.29$, $p = 0.015$; condition map (56, 1), $F = 1.34$, $p = 0.251$, n.s.; condition*condition order (56, 1), $F = 8.52$, $p = 0.005$.
10. Repeated measurement: condition (56, 1) $F = 5.31$, $p = 0.025$; condition order (56, 1) $F = 4.25$, $p = 0.044$; condition map (56, 1) $F = 1.63$, $p = 0.208$, n.s.; condition*condition order (56, 1) $F = 0.02$, $p = 0.893$, n.s.
11. Repeated measurement: condition (17, 1), $F = 5.57$, $p = 0.030$; condition order (17, 1), $F = 1.13$, $p = 0.302$, n.s.; condition*condition order (17, 1), $F = 0.00$, $p = 0.951$, n.s.

12. Repeated measurement: condition (17, 1), $F = 7.03$, $p = 0.017$; condition order (17, 1), $F = 4.04$, $p = 0.061$, n.s.; condition*condition order (17, 1), $F = 0.94$, $p = 0.345$, n.s.
13. We can relate these findings to the barriers and enablers for the development of shared understanding (Kleinsmann and Valkenburg 2008). The interactive table enables co-design participants to democratise expert knowledge (cf. 'The availability of specialised knowledge within the company', organisation level), and to co-operate with each other (cf. 'The ability of the actor to make a transition of knowledge', 'The empathy of the actor about the interest of a task', 'The view of the actor on the design task', 'The equality of the language used between the actors', 'The view of an actor on the process to follow', 'The prospect of the actor on the task of the other actors', actor level). In addition, participants develop a shared understanding of ways to co-operate productively on their task ('The efficiency of information processing' and 'The controllability of product quality', project level).

References

Badke-Schaub, P., A. Neumann, K. Luache, and S. Mohammed. 2007. Mental Models in Design Teams: A Valid Approach to Performance in Design Collaboration. *CoDesign* 3 (1): 5–20.

Boos, M. 2007. "Optimal Sharedness of Mental Models for Effective Group Performance." *CoDesign* 3 (1): 21–28.

Bucciarelli, L. 1994. *Designing Engineers*. Cambridge, MA: MIT Press.

Den Haag. 2010. http://www.denhaag.nl/home/bewoners/to/Samenspraak.htm

Ehn, P. 1990. *Work-Oriented Design of Computer Artifacts*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Friedland, G., and D. Van Leeuwen. 2010. "Speaker Identification and Diarization." In *Semantic Computing*, edited by P. Sheu, H. Yu, C. V. Ramamoorthy, A. K. Joshi, and L. A. Zadeh, 115–130. Hoboken, NJ: Wiley–IEEE Press.

Gosling, S. D., P. J. Rentfrow, and W. B. Swann. 2003. "A Very Brief Measure of the Big-Five Personality Domains." *Journal of Research in Personality* 37: 504–528.

Greenbaum, J., and M. Kyng. 1991. *Design at Work: Cooperative Design of Computer Systems*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kleinsmann, M. 2006. *"Understanding Collaborative Design."*, PhD thesis, Delft University of Technology.

Kleinsmann, M., and R. Valkenburg. 2008. "Barriers and Enablers for Creating Shared Understanding in Co-design Projects." *Design Studies* 29 (4): 369–386.

Kleinsmann, M., R. Valkenburg, and J. Buijs. 2007. "Why Do (n't) Actors in Collaborative Design Understand Each Other? An Empirical Study Towards A Better Understanding of Collaborative Design." *CoDesign* 3 (1): 59–73.

Post, W. M., M. A. A. Huis in 't Veld, and S. Van den Boogaard. 2008. "Evaluating Meeting Support Tools." *Personal Ubiquitous Computing* 12: 223–235.

Sanders, E. B. N., and P. J. Stappers. 2008. "Co-creation and the New Landscapes of Design." *CoDesign* 4 (1): 5–18.

Scott, S. D., K. D. Grant, and R. L. Mandryk. 2003. "System Guidelines for Co-located, Collaborative Work on a Tabletop Display." In *Proceedings of the Eighth European Conference on Computer Supported Cooperative Work*, edited by K. Kuuti, E. H. Karsten, G. Fitzpatrick, P. Dourish, and K. Schmidt, 159–178. Norwell, MA: Kluwer Academic Publishers.

Steen, M. 2012. "Human-Centred Design as a Fragile Encounter." *Design Issues* 28 (1): 72–80.

Steen, M. 2013. "Co-design as a Process of Joint Inquiry and Imagination." *Design Issues* 29 (2), 16–29.

Steen, M., J. Buijs, and D. Williams. 2013. "The Role of Scenarios and Demonstrators in Promoting Shared Understanding in Innovation Projects." *International Journal of Innovation and Technology Management*, forthcoming.

Steen, M., M. Manschot, and N. De Koning. 2011. "Benefits of Co-design in Service Design Projects." *International Journal of Design* 5 (2): 53–60.

Vosinakis, S., P. Koutsabasisa, M. Stavrakisa, N. Viorresa, and J. Darzentas. 2008. "Virtual Environments for Collaborative Design: Requirements and Guidelines from a Social Action Perspective." *CoDesign* 4 (3): 133–150.

Wang, X., and R. Chen. 2009. "An Experimental Study on Collaborative Effectiveness of Augmented Reality Potentials in Urban Design." *CoDesign* 5 (4): 229–244.