The application of conjoint measurement as a dynamic decision making tool in a Virtual Reality environment

THE APPLICATION OF CONJOINT MEASUREMENT AS A DYNAMIC DECISION MAKING TOOL IN A VIRTUAL REALITY ENVIRONMENT

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Abstract

This paper describes an innovative aspect of an ongoing research project to develop a virtual reality based conjoint analysis system. Conjoint analysis involves the use of designed hypothetical choice situations to measure subjects' preferences and predict their choice in new situations. Conjoint experiments involve the design and analysis of hypothetical decision tasks. Hypothetical alternatives, called product profiles, are generated and presented to subjects. A virtual reality presentation format has been used to represent these profiles. A profile consists of a virtual environment model and dynamic virtual objects representing the attributes with their respective levels. Conventional conjoint choice models are traditionally based on preference or choice data, not on dynamic decision making aspects. The status of this new approach will be described.

1. Introduction

Conjoint analysis or experimental choice analysis represents a widely applied methodology for measuring and analyzing consumer preferences (Carrol and Green, 1995). Conjoint analysis is a generic term coined by Green and Srinivasan (1978) to refer to a number of paradigms in psychology, economics and marketing that are concerned with the quantitative description of consumer preferences or value trade-offs (Timmermans, 1984; Louviere, 1988). Conjoint analysis sometimes referred to as stated preference modelling involves the use of hypothetical choice situations generated according to the principles underlying the design of statistical experiments to measure subjects' preferences, examine consumer behaviour and/or predict their choice in new situations (Oppewal, 1995). In a conjoint study, a researcher (1) selects the characteristics (attributes) that are assumed to influence the choice behaviour of interest, (2) classifies these attributes into numerical or categorical levels, and (3) combines these attribute levels into profiles according to some statistical design.

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Implicitly, it is assumed that choice alternatives can be viewed as a set of attributes. Subjects are assumed to trade-off the attributes of interest according to some algebraic rule to arrive at an overall preference for each profile. In order to estimate the preference function, a set of profiles designed according to some experimental design is presented to subjects who are requested to express their overall preference. While a verbal description might be a valid means of describing profiles in many contexts, one could argue that some attributes are better presented visually.

A framework for a virtual reality based system of conjoint analysis has been outlined in Dijkstra *et al* (1996). Such a system is of particular interest when subjects have to experience the context of choice and/or the attributes describing the choice alternatives. To take this argument one step further and to explore the possibilities of using this framework as a decision-making tool for virtual wayfinding environments is described in Dijkstra *et al* (1997). This paper explores the essentials of this methodology to utilize the application of conjoint measurement as a dynamic decision making tool in a VR environment.

The paper is organized as follows. First, we will discuss some basic principles of conjoint measurement and virtual reality and their integration, and also their integration. Then, in section 3, we will look back at some simple illustrations of conjoint experiments. This is followed by a section about decision making. Finally, we draw some conclusions.

2. Conjoint Measurement & Virtual Environment

1.1. CONJOINT MEASUREMENT

Conjoint analysis is a family of related for measuring consumer preferences or choice behavior. It helps to understand why consumers prefer or choose certain products (or services or new conditions).

1.1.1. Traditional conjoint analysis

The application of conjoint analysis technique implies the study of the joint effects of multiple product attributes on product preferences or product choice. The researched products (or services or new conditions) are described in terms of product profiles. Each profile is a combination of attribute levels for the selected attributes. Conjoint analysis has two major objectives: (1) to determine the contributions of predictor variables (attribute levels) to consumer overall preferences, and (2) to establish a valid model of consumer judgments useful in predicting the consumer acceptance of any combination of attributes, even those not originally evaluated by consumers (Hair *et al*, 1995).

In order to achieve these objectives, coefficients called 'utilities' (or part-worths) are estimated for the various attribute levels making upon the alternatives of interest by decomposing measured preferences for product profiles into these part-worth utilities according to some a priori defined combination rule which specifies how subjects are assumed to integrate those separate part-worth utilities to arrive at an overall preference or choice. The profile utility is an overall utility or 'worth' of a profile calculated by summing all utilities of attribute levels defined in that profile.

$$U_j = \sum_{i=1}^{N} x_i \quad ,U_j = \text{overall utility of the profile alternative j.}$$
$$x_i = \text{'part worth' of the i-th level of the x-th attribute}$$
$$N = \text{number of attributes}$$

Figure 1. Preference measurement in conjoint analysis

The estimation of these part-worth utilities is based on experimental designs.

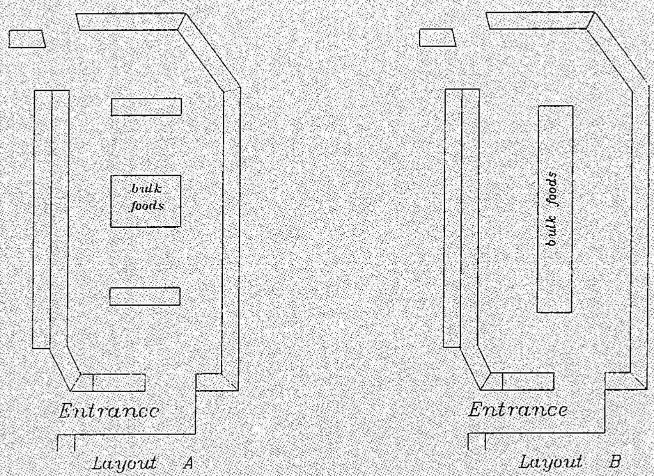
1.1.2. Experimental designs

Profile construction in conjoint analysis involves determining which attributes to present to subjects, and how to present these attributes. In a conjoint experiment, first the key dimensions (attributes) of products or services are defined. Next, the specific levels of each attribute are specified. The chosen attributes and their levels should be realistic and relevant to the problem. Also, the ultimate definition of attributes and their levels will be influenced by the possibilities of constructing a suitable experimental design. That is, the design should satisfy the necessary and sufficient conditions, required to estimate the assumed preference or choice model that describes the way in which subjects are assumed to arrive at some choice or preference. Traditionally , in axiomatic conjoint measurement, the focus is on testing the structure of preference functions, i.e., whether preference functions are additive, multiplicative or combined additive-multiplicative. More recently, preference functions are estimated from experimental design data using an appropriate multivariate statistical technique. Conjoint experiments thus require subjects to express their preference for various experimentally designed, hypothetical alternatives in terms of their most relevant attributes. Two or more fixed levels are defined for each attribute and these are combined to create different profiles. Subjects are invited to express their preference for the experimentally varied profiles by rating or ranking these in terms of overall preferences. Alternatively, subjects may be asked to choose the profile they like best. Preference functions are estimated from this data. Obviously, the number of possible combinations increases exponentially with an increasing numbers of attributes and/or levels. Fortunately, the data collection can be greatly reduced by using fractional factorial design techniques (Montgomery, 1991). In analysis-of-variance terms, this often means that only main effects are estimated. Therefore, an experimental design is defined by an optimal subset of profiles of a fractional factorial design, which can be presented to a subject without negatively influencing responses in terms of boredom or fatigue.

1.1.3. Design and analysis of conjoint experiments

The current discussion, strictly speaking, relates to a preference model. A subject's preferences are decomposed into part-worth utilities, which represent the contribution to the individual's overall preference or utility of the attribute levels that were used to generate the profiles. If one wishes to construct a choice model, the attribute profiles have to be placed into choice sets. Subjects are then asked to choose one alternative from each choice set, or alternatively, to allocate some fixed budget among the choice alternatives (Oppewal and Timmermans, 1991).

We will illustrate some of the above issues by presenting a simple example.



Let us assume that a retailer has to plan the first aisle after passing the entrance in a supermarket. In making his decision, the retailer has to consider a number of factors. These factors will be presented by attributes and their levels. Let us assume that the following attributes and their levels are important:

- *Merchandise indication (MI)*
  do you want that there's a merchandise category indication near at a merchandise area (for instance 'fresh meat', 'cheese chop'), which is good visible at a distance?
  No = no indication, Yes = indication
- *Bargain offers near at the entrance (BOE)*
  do you want the bargain offers are exposed near at the entrance?
  No = not desirable, Yes = desirable
- *Layout (LO)*
  which layout do you prefer?
  A = layout A, B = layout B

Summarized, we have the following attributes with their levels:

Attributes	*Levels*
MI	Yes, No
BOE	Yes, No
LO	A, B

This scenario results in 8 ($=2^3$) possible profiles.

Profile 1 .... Profile 8

- MI : No
- BOE: No
- LO : A

Profile 8

- MI : Yes
- BOE: Yes
- LO : B

The question then is the choice of the respons format

In case of ratings data, subjects are requested to rate these profiles on some psychological scale, this format provides information about both order and degree of preference.
For example, a question could be: What is your opinion about this arrangement?

Profile 1

- MI : No
- BOE: No
- LO : A

X
1 2 3 4 5 6 7
very poor — average — very good

In case of choice data profiles are placed into choice sets and subjects are asked to choose among two or more profiles.
For example, which profile do you prefer?

Profile 1

- MI : No
- BOE: No
- LO : A

Profile 8

- MI : Yes
- BOE: Yes
- LO : B

Finally, in case of budget allocation, budget-points will be allocated among a set of profiles. For example, a budget allocation with profiles 2 and 7 as hypothetical alternatives, could be:

Allocate 20 budget-points	Basic Profile	Profile 2	Profile 7
	.... points	.... points	.... points

'Design Descriptions'
In experimental designs, attributes are termed 'factors'. The goal is to structure the data collection process in such a way that the identification possibilities for the utility function are maximized. In a full profile approach, we distinct a full factorial design and a fractional factorial design. A Full Factorial (FF) design contains descriptions of all possible combinations of attribute levels. It enables one to independently estimate all main effects and all interaction effects of each attribute. On the other hand, a Fractional Factorial design contains a fraction of a FF design. It assumes that certain interaction effects among the attributes are not statistically significant.

The following simple example will illustrate this. Suppose we have 3 attributes with 2 levels each, with level indications 0 and 1. A 'Full Factorial' (FF) design exists of all possible combinations.

Combination/Profile	Levels
1	0 0 0
2	0 1 0
......	
8	1 1 1

A 'Fractional Factorial' design exits of a fraction of a FF design, for instance:

Fraction 1		Fraction 2	
Profile	levels	Profile	levels
1	0 0 0	2	0 1 0
4	0 1 1	3	0 0 1
6	1 1 0	5	1 0 0
7	1 0 1	8	1 1 1

1.2. VIRTUAL ENVIRONMENT

In architectural and real estate simulations, it is interesting to get as realistic as possible impressions of a designed model by means of virtual reality. Consideration can be given to modeling autonomous objects and to the simulation of operations on objects. The visionary design studio embedded in a VR environment is an example of a vision of a new design environment, equipped with a modeling tool that allows intuitive and interactive modification of intelligent objects (Engeli and Kurmann, 1996).

What distinguishes VR is the crucial role played by the user. That is, the user has an active involvement and is not a passive observer. The user becomes an essential participant in the virtual environment with unlimited freedom to explore, control and change it. The only limits are those set by the designers of the virtual environment. VR techniques can be used to create an interface that allows modeling in an intuitive way. Through the imitation of behavioral aspects of the real world, the interface gets predictable and recognizable characteristics. In fact, simulation based design technologies within VR technologies enhances the capabilities of the design to manufacturing process. The product can be visualized, design changes can be made, and new concepts, without the traditional expense of prototyping, can be tested.

This last aspect is subject of another area of research and application area for VR. Advances in VR techniques now enable consumers to be immersed in new environments and experience new products or services. This aspect is of interest to get a better insight into consumer behavior and support product testing in its most general meaning.

1.3. INTEGRATION OF CONJOINT MEASUREMENT AND VIRTUAL ENVIRONMENT

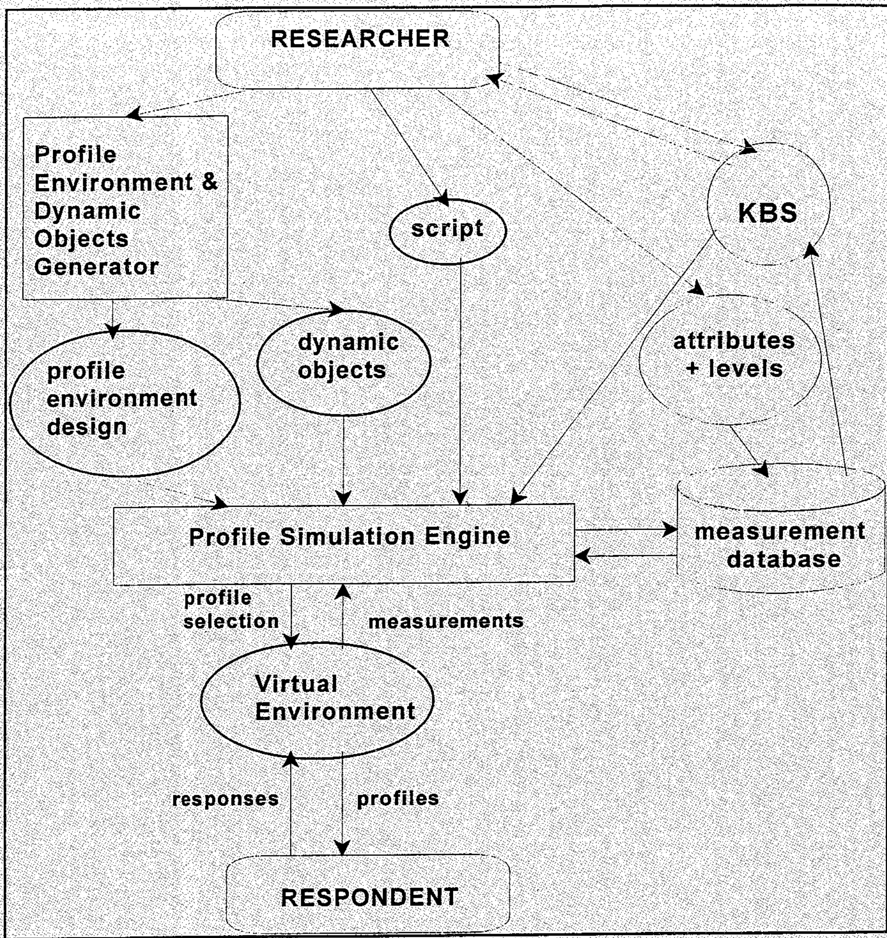


Figure 2. CA & VR system approach

Most studies of conjoint analysis involve verbal descriptions of product profiles, although some studies have used a pictorial presentation of product profiles. Klabbers *et al* (1996) propose a multimedia engine for stated choice and preference experiments, which enables researchers to use varying presentation formats thereby measuring the influence of the presentation format. In this research project, profiles presented by a virtual reality presentation format, are for conjoint measurement. A profile consists of a virtual environment model and dynamic virtual objects representing the attributes with their respective levels. Each attribute level is a different state of the concerned virtual object. In the case of a virtual walk through a building design, the system can be viewed as a visual simulation of the environment. In this research project, the focus is on profiles presented by a virtual reality presentation format, thereby emphasizing yet other aspects of decision-making compared to multimedia engines.

The ultimate objective of the research project is to investigate and develop possibilities of a VR-DIS (which is an acronym for Virtual Reality - Distributed Interactive Simulations system) - environment for those cases where choice behavior and decision-making processes of consumers may be of importance. This is based on the idea that a VR-presentation of a design is not only a matter of simulation and visualization, but virtual reality research could be a key to a mechanism for measuring responses particular design characteristics. One means of measurement could be to have subjects choose between profiles by exploring the building features in the virtual environment. Taking prospective users of a building into account, the CA&VR concept could be a decision-making tool in choosing among particular design variant characteristics. Briefly, the scheme at the beginning of this part of the section, shows the CA&VR concept.

3. Simple Illustrations of Conjoint Measurements

In Dijkstra *et al* (1996) and Dijkstra *et al* (1997) a wayfinding illustration of conjoint mmeasurement was given. Wayfinding concerns the spatial organization of the setting, the circulation system and architectural as well as graphic communication. It can be described as all perceptual, cognitive, and decision-making processes necessary to find one's way. That is, it is as a mental and physical act of reaching destinations and is best defined as spatial problem solving, comprising three specific but interrelated processes (Arthur and Passini, 1992): (i) decision making, the development of a plan of action, (ii) decision execution, which transforms the plan of action into appropriate behavior at the right place in space, and (iii) information processing understood in its generic sense as comprising environmental perception and cognition, which, in turn, are responsable for the information of the two previous decision-related processes.

In addition to the spatial problem solving process aspect, there is also the design aspect of wayfinding. The design part provides information, identified by three aspects: (i) content of information, (ii) location of information and (iii) form of information. Content and location of information are related to decision making and decision execution. The form of information comprises environmental perception and cognition and is related to information processing.

In the design part of wayfinding, the emphasis is on the graphic components. In the experimental designs of the illustrations only the design part of wayfinding, especially graphic communication as part of the environmental communication would be considered. In the first illustration, information about the settings as well as information directing to the location and information identifying the destination would be emphasized.

Attribute	Level	Description
◊ Orientation	⇒ Floor plan ⇒ Directory	Ability to perceive an over-view of a given environment
◊ Directional signage	⇒ Text besides arrow sign ⇒ Text inside arrow form	Guides people along a desig-nated route to a destination
◊ Identification	⇒ Name ⇒ Sign with name	Information provided at the destination

For instance:

Identification: Name

Identification: Sign with name

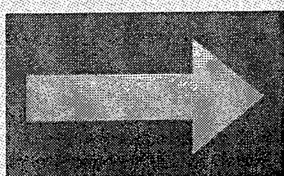
Figure 3. Design specifications Illustration 1

In the next illustration, we will focus on information directing people to the way out. This would be realized by graphic communication on exit-signs. How to test exit-signs for their suitability, is the underlying idea. Besides the aesthetic aspect we could measure, we would also have a mechanism to measure the effectiveness of exit-signs.

Attribute	Level	Description
◊ Directional Exit-sign Location	⇒ Fixed at wall, column ⇒ Fixed at ceiling	Guides people along exit-route to exit
◊ Directional Exit-sign Type	⇒ Exit sign I ⇒ Exit sign II	Guides people along exit-route to exit
◊ Exit Identification	⇒ Exit Font I ⇒ Exit Font II	Information provided at exit

For instance:

Exit sign Type I



Exit sign Type II

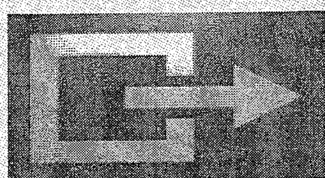


Figure 4. Design specifications Illustration II

Especially, exit-signs could be tested in a fire drill simulation. In that case, we have an example of virtual wayfinding.

4. The Decision Making Aspect

4.1. DYNAMIC DECISION MAKING

Decision making is the heart of human behavior (Kerstholt, 1996). The main goal of behavioral decision making is to explore how subjects make their choices. Many real-world decision tasks are dynamic in nature, which often means that the decision context changes over time. Dynamic task situations are rather difficult to model, which can be traced back to the exponential growth over possible outcomes over time: as the decisions influence each other, each combination of decisions made over time has its own expected value. The main reason for modeling the task is to have a normative solution to which subjects' choices can be compared. We can summarize some characteristics of dynamic tasks:

- The environment in which the decision is set may be changing, either as a function of the sequence of decisions, or independently of them, or both.
- Decisions need to be made in real-time. This factor added an extra dimension to dynamic decision making, as the decision maker has to consider the dimension of time explicitly. It is not enough to know what should be done but when it should be done. Thus, in dynamic tasks subjects typically control a changing system, they receive feedback about the state of the system and they need to make a sequence of decisions.
- Dynamic decisions change over time. The main effect of the changing nature of dynamic tasks is that the time dimension has to be taken into account explicitly.

The given illustration of virtual wayfinding is really a dynamic decision making process. Decisions will be made real-time and also the time dimension had been considered. Indications like signs presented as different virtual objects could be tested for their suitability. After a fire-alarm and during a smoke production an individual should find his way to the exit within a certain period. Thus, the time-pressure aspect had been involved. Maybe, we could get answers on the questions how subjects deal with dynamic tasks and about how adaptive their behavior is. The perception of virtual objects in the virtual environment gives the necessary feedback. The illustration of virtual wayfinding is a matter of functional simulation. As a consequence, a decision about the actual signage can be proposed. It is possible that a potential difference between this actual signage and the preferred signage is the consequence.

Another aspect of decision making is the distinction between action-oriented decision making and judgment-oriented decision making. Due to the time pressure, the decision making is more action-oriented such as during a smoke production after a fire-alarm. Judgments about characteristics of architectural design features represented as virtual objects is a judgment-oriented decision making process, just like the exploration of virtual objects. On the other hand, the perception of graphic components of signage in the first illustration of wayfinding is more judgment-oriented.

4.2. METHODOLOGY

Within the context of VR-DIS, the aspect of dynamic decision making is an unconventional part of ongoing research. This aspect will be realized in the development of a conjoint and a virtual reality system. Besides a profile generation part, a profile simulation part and a data-analyzing part, the system essentially consists of a virtual environment part for a subject's virtual walk-through of selected profile alternatives. Such an application is likely to better incorporate the idiosyncrasies of virtual reality systems, but does not satisfy the typical assumptions underlying conjoint models.

Conjoint analysis originally was developed to measure users' utilities for multi-attribute choice alternatives. The design of the experiments should allow one to reflect the assumed preference function or choice model. Consequently, to measure preferences or utilities, subjects are requested to rank or rate the experimentally varied attribute profiles on some preference scale. The observed values can then be decomposed into the utility contributions of the attribute levels. Similarly, if the focus is on testing an assumed choice model, then the profiles are placed into choice sets and subjects are requested to choose from each choice set the alternative they like best.

These response formats can also be applied to the problem of wayfinding if one is primarily interested in understanding the contribution of attributes of the guidance system on users' preferences. However, if may well be that the researcher's or designer's interest goes beyond this problem. For example, the question of interest might be whether users were successful in finding an exit, or in the time it took them to find an exit. In these situations, the dependent variable of the model shifts from a ranking, rating or choice to a dichotomous yes/no variable or a time variable respectively. The multivariate statistical analyses that are commonly applied in conjoint analysis are no longer appropriate for these situations and hence alternative techniques need to be chosen.

If the focus of interest concerns the question whether users are successful in finding an exit, then the binary logit model is a candidate for analysis. It allows one to estimate the contribution of attribute level on the probability that users find an exit. Hence, the result of the analysis may be used to identify the most critical attributes of the guidance system. Alternatively, if the focus of interest concerns the issue of how long it takes to find an exit, the dependent variable of the model consists of positive numbers only. Poisson regression analysis is an appropriate multivariate analysis tool to analyze such data. In this case, the coefficients of the regression equation indicate the effect of the attribute levels on the time it takes to find an exit.

5. Remarks on Choice Models and Exploration of the Virtual Environment

We will make some briefly comments on developing a conjoint analysis based virtual reality system.

5.1. CHOICE MODELS

Choice models are suitable for the use of experimental designs to construct hypothetical products or services, and observe subjects' choices. Hereby, the researcher has control over the attributes and their correlation. The basic principle is:

- Ask subjects to choose from Profile A and Profile B.
- Choice of A vs. B indicates preference of the preferred Profile attribute levels.
- Systematically varying attribute levels allows building models of such trade-offs.

Subjects are assumed to attach an overall value to a choice alternative. This utility is arrived at by combining evaluations of attributes. Originally, choice sets will be formed and subjects decide which profile alternative from the choice set is chosen. In a virtual reality based conjoint measurement experiment, it is not appropriate to choose from more than one choice set without negatively influencing responses in terms of boredom or fatigue. For subjects, only a small number of reduced choice sets could be dealt with. If we want to perform an experiment on this manner, many mores subjects are needed. Adaptation of accepted utility functions needs to be developed.

5.2. EXPLORATION OF THE VIRTUAL ENVIRONMENT

A virtual environment is very convenient to explore virtual objects. By clicking a virtual objet, a specific attribute level will be displayed. Each attribute will be presented by a virtual object and each virtual object has a number of appearances. Each appearance is a level of the attribute. By exploring the attributes in this way, the subjects' preferred profile can be generated. Due to the conjoint measurement in a virtual environment, it is also feasible to record a subjects' walk through a virtual environment. Data about actions, decisions, judgments, perception and time-span can be collected and evaluated. Obviously, a virtual environment is a particular environment for applying conjoint measurement experiments. The conjoint measurement can be affected by:

- Experience. That is, experience about virtual reality, experience about the model, and experience about virtual reality techniques. It is important that the virtual environment is familiar to subjects participating in the conjoint measurement experiment.
- Effects of attributes that are of interest may be confounded with the effects of other factors in the virtual environment.
- Also the order of displayed attributes as virtual objects can act on the measurement.

6. Conclusion

Recent development in virtual reality systems allow the creation of interactive environments that can be used to observe user reactions and decision making in not yet existing environments. It will be evident that such systems offer the potential of an evaluation of building performance in advance. The power of such systems can be enhanced if a modeling approach underlies the observations of user reactions. Such an approach offers an opportunity for generalizing the findings beyond the actual environments that were incorporated in the virtual environments.

In the present paper, we have discussed such a framework for interactive virtual environments and illustrated its potential use in the context of wayfinding in buildings. We proposed to link the technology of virtual reality systems to conjoint analysis and discussed the implications of such an endeavor. We argued that the methodology for conventional conjoint analysis is well developed, but that for some more advanced problems, additional methodology needs to be developed.

The ultimate test of the relevancy of such systems, however, depends on empirical testing. One critical issue relates to the question whether user behavior in virtual reality is systematically related to user behavior in real-world situations. We hope to report on such research in the near future.

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