Visualisation techniques, human perception and the built environment

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ABSTRACT

Historically, architecture has a wealth of visualisation techniques that have evolved throughout the period of structural design, with Virtual Reality (VR) being a relatively recent addition to the toolbox. To date the effectiveness of VR has been demonstrated from conceptualisation through to final stages and maintenance, however, its full potential has yet to be realised (Bouchlaghem et al, 2005). According to Dewey (1934), perceptual integration was predicted to be transformational; as the observer would be able to 'engage' with the virtual environment. However, environmental representations are predominately focused on the area of vision, regardless of evidence stating that the experience is multi sensory. In addition, there is a marked lack of research exploring the complex interaction of environmental design and the user, such as the role of attention or conceptual interpretation. This paper identifies the potential of VR models to aid communication for the Built Environment with specific reference to human perception issues.

Keywords: Architecture, Communication, Perception, Virtual Reality.

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INTRODUCTION

According to Tversky et al (2006) models primarily exist in the mind and are expressed through visualisations to provide tangible impressions of cognitive thought. This form of communication has endured from ancient cultures to modern day society and is considered to be a useful tool to augment the expression of ideas or communication. However, they can vary in both complexity and clarity, and, the degree of both is indicative of the skill of the purveyor of the representation (see Tversky, 2001, 2005 for further discussion). Therefore, visualisations have evolved to serve innumerable objectives by externalising thought and rendering it visible to others which can explain, refine, encapsulate, elaborate, investigate and facilitate ideas to a wide range of parties.

With specific reference to the Built Environment, the effectiveness of visualisations can identified early in a project in some instances as conflict or errors can be identified and corrected before real space construction occurs (Westerdahl et al, 2006). In addition, the use of Virtual Reality (VR) has the value added potential to design and test environments for specific users. However, the measurement and definition of a successful visualisation is a more complex issue, especially in relation to new tools such as VR. However, there are additional challenges in the use of VR as a visualisation tool because the knowledge and research of what constitutes an effective visualisation lags behind the rapidly changing technology (Orland et al, 2001).

ARCHITECTURE AND VISUALISATION TECHNIQUES

Traditionally, the techniques adopted to represent architectural images are heavily reliant on the technology available at that time, which is generally reflected by the architectural design of the era (Giddings & Horne, 2002). Most recently, the techniques for representing architectural visualisation have became more sophisticated and are now powerful tools, chiefly through the introduction of VR (Wergles & Muhar, 2009). Nevertheless, the ‘science’ behind visualization techniques appears to be predominantly driven by the methodologies utilised to communicate these images, with the impact of user perceptual evaluations distinctly lagging (Zube et al, 1987). This is supported by the distinct paucity of evidence identifying the effectiveness of visualisations as a communication tool, despite an emphasis in the Egan Report (1998) which encouraged innovation and improving design processes through communication.

The evolving building process necessitates the importance of evaluating human cognition to accommodate the challenges of cultural change through collaboration, architectural development and diverse populations in order to improve productivity amidst global competition. Large casts of experts and novices now exist, from heterogeneous backgrounds, depending upon the size of the project (Muramoto et al, 2008). Such changes dictate considerable attention to the communication processes of design and expertise in a discipline that relies heavily on consultation through a visual media. Recent technological developments acknowledge the potential of exciting developments with 3D, for instance, 4D (3D+time/scheduling), 5D (4D+cost) through to nD modelling, where the nth element assimilates sufficient components to provide a ‘cradle to grave’ lifecycle model for portrayal and projection purposes (Bouchlaghem et al, 2005; Greenwood et al 2008). However, there is relatively little information concerning the interaction between the representations and the cognitive processes of the user from a communication, encoding and interpretative perspective. Zube (1991) states that the single discipline approach within environmental research is inadequate, due to the portrayal of the individual as a static observer, thus not accounting for the complexity of human perception. This slant reduces comparisons between the representations and reality to purely visual judgements, despite well established knowledge that individuals learn about their environment from other modalities, such as motor input (Reiser et al, 1995). More importantly, individuals have very limited attention through which to view the world, resulting in the utilisation of past knowledge and ignoring the constructive nature of perception. For instance, tangible world objects are also mental objects, as they become stored in memory. In order to simplify what is seen, object grouping appears to be fundamental to perceptual and memory organising principles, which results in inferences of what is available or predicted, in both static and motion imagery. Therefore the main thrust of the issue with representations should be: what do individuals 'see', and can algorithms be developed in the field of visualisations in order to identify and enhance this process?

Perversely, the complexity of visual perception only becomes apparent through visual errors or miscommunication. In the building industry, where "even experienced architects make design errors," the importance of shared understanding is imperative as the consequences of such errors can linger and be costly (Lee, Eastman & Zimring, 2003). Therefore, a focus is required on the key factors which contribute to shaping what is perceived within the context of visualisation techniques available in architecture. In addition an acknowledgment of the restrictions associated with the current techniques is required in order to augment the impact of VR.

VIRTUAL REALITY (VR)

VR is considered, by many, to be the most significant technological change and critical to scientific understanding as it offers great potential for both research and a wide variety of applications such as aerospace, surgery, military and industrial training for hazardous conditions (Stone, 2000; Burdea & Coiffet, 2003).

However, within the area of Built Environment, attitudes towards VR appear to be mixed, with accounts of academics adhering resolutely to the traditional fragmented methods, even though established methods, such as sketching, have been demonstrated to inhibit exploration of design with novices (Giddings & Horne, 2008). Whilst it is acknowledged that sketches facilitate design, differences in perception are noticeable between the individual groups, thus suggesting that the technique might only be appropriate amongst an elite group of experts, if used as a solitary representation (Suwa & Tversky, 1997). Similar criticisms apply to additional methods, for instance perspective drawings are reported by non-architects as the least realistic and accurate form of representation (Bates-Brkljac, 2008). In addition, physical scale models, whilst being a useful tangible representation, allowing individuals to encapsulate, investigate and facilitate ideas (Tversky et al, 2006) can be criticised for lacking environmental context. Conversely, photomontage (for review see Ervin & Hasbrouk, 2001) presented a high level of geometric accuracy and attempt to imitate real environment features by draping image layers over a 3D representation of the terrain. However, it has also been accused for being heavily laden with too much information, subject to bias and distortions through lens size and image dimensions (Bishop & Lange, 2005).

With this evidence then surely VR can only be seen as a necessary addition to enhance industrial communication, although the criticisms of photomontage possibly hint at potential obstacles associated with modern day technological developments. VR can facilitate perception by providing a platform to interact with the representations, unlike static information which can challenge the most able of individuals through enforced mental transformations such as mental rotations or shifts of perspective (Zacks and Tversky, 2005). However, the shift from pen and paper designs to computer based environments was, initially, merely a new technology adopted for an existing practice (Greenwood et al, 2008). Such a rigid transition to computer methodologies directly predicts that it will not improve shared understanding, which is fundamental for making joint decisions and for negotiating tradeoffs among competitive worldviews. Undoubtedly, VR should be considered the key factor for innovation, especially as it is now the preferred and anticipated media with which to convey ideas and visualisations (Pietsch, 2000). Benefits as a representation have already been reported, especially with lay persons in a neighbourhood participatory planning process (Al-Kodmany, 1999, Chen et al, 2002). In addition, in an area where increased globalisation generates a drive towards competitive advantage and efficiency, benefits, which include the elimination of the need to build prototypes and reduce costs in other areas, are well documented (Quayle et al, 2005).

However, the approach to utilising such a media requires adaptation to both client and user requirements through scientific knowledge. VR use, currently, is limited to "client walkthroughs, design reviews and the visualisation of construction sequences" (Dawood, 2009). Unsurprisingly, the 'pull' from industry is not at the level anticipated for the technology, which Dawood explains as due to perceived complexities and lack of agility associated with the technology. This would highlight a need to identify the complex and costly processes in relation to miscommunication expenditure.

In order to address the issues of miscommunication, simplicity and superfluous costs, further research is required to understand the criteria for 3D scenes and what should be incorporated in a representation. For instance, a complex balance between abstraction, accuracy and realism is required (Pietsche, 2000). Failure to do so could result in the unnecessary costs associated with the adoption of VR, resulting in industry utilising the tool, not to augment communication, but to create a 'Wow-Effect', which could inhibit communication further (Frost & Warren, 2000).

HUMAN PERCEPTION AND COGNITIVE CONSTRAINTS

Fundamentally, the mind infers beyond the information given (Bruner, 1957) resulting in perception of even the most uncomplicated entity being a complex, multifaceted process. This can be identified from illusions or systematic errors. There are several contributory factors involved in the process of perceiving such as, cognitive limitations, attention and interplays between past experiences, including one's culture, and the interpretation of the perceived event or object. Therefore, creating successful visualisations is challenging in order to provide a framework for effective collaboration and communication. Visual perception provides substantial support that the world individuals which 'see' is not the exact image but 'constructed' due to cognitive constraints. For instance, individuals are not passive recipients to their environment, taking selective 'snapshots', but actively interpret the environment. Therefore representations can never be neutral or just a static 'pictures', which should impact upon the form(s) of representation utilised.

Perception is not an isolated process nor is it solely connected to a 'visual memory.' An individual's awareness is determined by what they choose to attend, not merely on the stimulation entering the senses. It is also stated that attention binds information from the different modalities i.e. vision, hearing and motor, in addition to effort and touch, etc (Driver & Spence, 1998). Furthermore, the availability of cognitive resources influence the level of attention individuals can sustain towards an environment, of which there is much evidence in the 'looked but failed to see' phenomenon (Simons & Levin, 1998). Attention can be either exogenous, a typical bottom-up process, controlled by external stimulus presentation, or endogenous, a top-down controlled mechanism (Jonides, 1981), requiring the individuals attentional effort, such as the delivery of an object. Therefore, navigation in an environment is a complex interaction between the individual and the environment.

With specific reference to visualisations, it is pertinent to note that there are differing neural mechanisms between perception for recognition and perception for action, or goals (Milner & Goodale, 1992). This is an essential consideration as, whilst the aesthetics of a structure are considered to be important, buildings are rarely built for viewing purposes alone, thus placing greater emphasis on the need to test environments for usability. Also, mental spaces are not unitary, as spaces are perceived depending on the functions they serve. This raises the issue of whether Built Environment can rely solely on visualisations, when it is known that we know that individuals experience their environments through other sensory information, which integrates to provide a seamless experience of space. In addition, the regulation of the 'seamless experience' is also confounded further by even the most exact of replications failing to convey significant features of any given model due to the individual differences of the observers. For instance, what may be pertinent to one individual may well be overlooked by another.

Conversely, there is much evidence supporting the fact that individuals do not require exact replications of what they are observing. The change blindness phenomenon demonstrates that dramatic changes can be made to an environment and individuals would fail to notice, for example; when a person they were talking to was surreptitiously replaced by a different actor (Simons & Levin, 1998). In order to cope with the limited cognitive resources, individuals schematize their environment, accessing information from long term memory. Schematic representations, therefore, reflect an individual's cognition, through comparing features from objects. Whilst the level of resemblance plays an important role, some objects do not need to be exact resemblances. This could be demonstrated by exaggerating the size of buildings or entrances that have significant importance. However, such a visual adaptation could create further criticism of bias or distortion. In addition, for something to look 'right' is dependent upon contextual factors, expertise of the observer and the goal of the representation. As a result, effective visualisations need to address the psychological constraints and use them to make informed decisions and be augmented, by directing attention to the appropriate features, though light, colour, focus or even 'talk-overs.' This will ensure that the presentation of information adequately meets the needs of the specific user group through the identification of perceptual, cognitive and response-based mental representations.

Thus, a key factor when considering the approach and level of detail, in addition to acknowledging the various psychological constraints, is to identify the purpose of the visualisation and target audience of the model. Undoubtedly, VR has great potential; however, before one can project and develop the technology to its true potential, key consideration must be given to the inherent perceptual and cognitive capabilities and limitations of the intended users and audience. Failure to do so will generate a substantial risk of either inducing avoidable expenditure or, making costly errors.

IDENTIFYING COGNITIVE MODELS

Algorithmic development can successfully aid identification of the correct approach towards developing and establishing cognitive representation principles (Tversky et al, 2006). Research into cognitive and visualisation techniques can be combined in three cyclical steps:

- Distinguishing the mental representations individuals have for a specified domain and the visual method used to illustrate it, identifying domain cognitive design principles.
- Development of algorithms that create effective visualisations based on the domain cognitive design principles.
- Testing the visualisations to ensure that they adequately convey the desired information.

As stated previously, there is no unitary theory of perception and recognition that can completely define what individuals 'see'. It could be argued to be a complex interaction between bottom-up direct information and top down Gestaltist and constructivist processing. This is complicated further through the processing of the information and the limitation of cognitive resources, in addition to anticipation that has been identified as being directly associated to impending attentional focus (Rowe & McKenna, 2001).

To capture this complex interaction, Tversky et al (2002) state effective visualisations should conform to two general principles:

Principle of Congruence – desired mental visualisations should comply with the physical features, content and structure of the external representation.

Principle of Apprehension – the external representation should be readily and accurately perceived and comprehended.

Compatibility between the information presented and the cognitive representations of all of the users involved will result in a faster, precise and dependable performance. To demonstrate the extent of these principles, consider the visualisations already in use within built environment processes. The design of a good representations is perceived to be a challenge, some being praised for clarity but others criticised as being vague and perplexing. Unsurprisingly, given what is known about visual perception, many at first appear to fulfill the congruence requirement but can then fail either during the construction or utilities stage. In a situation, where a cast of diverse individuals are involved in the decision making process, many may well agree that an external model matches their internal expectations, only to discover that there is conflict in the design at a later stage. Mis-communication often exists between the individuals involved in different domains and procedures which highlight the importance of shared understanding through the creation of opportunities to test false assumptions.

The failures of any visualisation may occur because the models violate the Apprehension Principle too. Representations can be too abstract or out of context or presented from a perspective that distorts or masks certain features. And, unlike real space, cannot be explored in the way that is known how individuals learn about their environments.

REVEALING COGNITIVE DESIGN PRINCIPLES

Ensuring that visualisations are congruent with mental representations involves cognitive psychological techniques to reveal those internal mental representations. A common approach in cognitive psychology is the measurement of reaction times; if the interpretation is congruent, representations will be more accurate and responded to faster than incongruent representations. For example, visualisations that are presented in a different perspective or topographical view will have to be mentally transformed to correspond with alternatively presented visualisations. Similarly patterns of error could be analysed to clarify the problem areas. Another example concerns seeing function in structure. This appears to be a characteristic of expertise across various domains such as engineering diagrams (Heiser & Tversky, 2004) and also in novice architects (Suwa & Tversky, 1997). Whilst this indicates that this is a skill that can be fostered, it also highlights the inefficiency of such an approach when communicating with laypeople or experts from different domains. There is to date no documented evidence that these skills can be transferred between the experts from various domains without repeated exposure.

Protocol analysis could investigate more complex mental models, to reveal how individuals perceive depictions. This provides rich data and also captures the natural way that communication occurs through the analysis of common descriptors and the differences. The common structure would reveal an underlying mental model which could then be used as a guideline to develop and test by users in order to qualify as design principles and, ultimately, inform what is chosen for specified algorithms.

This could provide a systematic basis from which to direct future VR research efforts and advance the technology to meet the needs of its users more effectively.

REVEALING COGNITIVE DESIGN PRINCIPLES FOR VR

The introduction of VR has undoubtedly created potential for both design and communication. Whilst it is generally taken for granted that new tools augment cognition, building exact replications can also be costly. They need to be produced in relation to what people actually aim to achieve with them, through testing and developing models.

Developing VR in the hope of making it more successful requires more than utilising lucrative processes from the previous methodologies in use; it is a matter of developing and testing visualisations that work. Therefore choosing a VR representation should incorporate the psycho-physical factors in order to maximise efficiency.

As previously stated, it would be false to assume that even the most accurate of visualisations will be most successful in replicating how individuals experience their environment. Tversky (1993) claims the most appropriate metaphor for a mental representation is a “cognitive collage,” as biases and errors or features omitted and simplifications are systematic, not random. This notion is not recent or specific to psychology experts, as Bishop (1992) stated that precedence was required to develop a framework to balance abstraction, accuracy and realism. Therefore how people think about objects and their spatial relations and needs to be investigated and tested across groups.

There is ample evidence, from experiments comparing purely visual judgements in VR and Real Space, that there are reliable discrepancies, and it is now widely recognized that perceptual judgments of particular spatial properties are different in VR than in the real world, even when real world distances are authentically portrayed (Campos et al, 2007). However, generally, empirical data comparing real space and VR focus on distance estimations and lack ecological validity, as participants are asked to just walk in real space or VR. However, people rarely walk in an environment without a purpose, which must impact upon executive and attentional resources utilised.

Most recently, Johnson et al (2009) addressed the issue of ecologically validity in spatial cognition by requesting participants to deliver an object in a role play scenario in real and virtual human mazes. The scenarios differed in urgency and desirability, such as delivering medication to a sick friend or delivering exam results to a friend, but opening the envelope only to find that they had failed everything! Participants took part in one task, to ensure that their experience did not transfer from one condition to another. Participants in the urgent scenario reported the path as being significantly longer than the participants in the non-urgent, but undesirable, scenario. Interestingly, the behaviour was identical in both Real Space and VR, thus supporting VR as a valid research tool for investigating space. Therefore, VR could not only be a valid surrogate for real world experiences but also provide a tool to augment design by testing buildings for usability before construction.

The potential of VR highlights the lack of vision in statements such as, error-free, unflawed representations were "neither possible nor worthwhile" (Ervin and Hasbrouk, 2001). VR as a communication tool requires research and investigation at relatively little cost. There is evidence to support experience of certain environmental conditions in quite simplistic Virtual Environments. For instance the 'segmentation' hypothesis (Sadalla & Magel, 1980), was replicated on a simple desktop environment (Jansen – Osmann & Berendt, 2002). This hypothesis claims that the increase in the number of right angled turns in an environment results in the perception of distance increasing in comparison to a straight path of the same length. In addition, the Johnson et al (2009) study utilised low cost real space and VR materials, indicating that fidelity also does not have to involve considerable expense.

In addition to vision and cognitive processes, the influence of motor input has also been identified as a contributory factor, and, Ruddle (2006) suggests that motor input is crucial for navigation and only moderate visual detail is required. However, it has also been established that visual flow plays a role in perceptual processes (Rieser et al, 1990). This raises the issue of utilising the appropriate VR system to mediate with the task, especially when given that individuals, most often, will change some of the features of their pace in accordance with the environmental features and the purpose of their journey.

Consequently an individual's notion of space is highly complex; it depends on their experience of a particular environment and the actions associated with it, which is then coupled with associative perceptual and motor processes. Different environments are crucial for different kinds of actions which are then dependent on different perceptions; these all have consequences for conception of space and the technology utilised for testing. Presently there is no framework to identify when passive visual walkthrough will suffice or when motor input is actually required.

Also, new technology has resulted in animations superseding static diagrams for conveying processes, currently providing timed construction animation sequences. However the reaction to this is mixed as whilst it has been found to make substantial savings and reduce time (Dawood, 2009); there is also evidence that animations generally fail to address their purpose (Tversky et al, 2002). Whilst one would imagine animations to fulfil the criteria of the Principle of Congruence as it conveys processes over time, there is substantial evidence indicating that animations are not always superior to their static counterparts (Tversky et al, 2002). Issues can occur when animations are too complex to be adequately perceived, for instance involving many moving parts; what is crucial is often the exact timing of the changes which the eye and the mind cannot accommodate in a short time scale. Novices often don't know where to look and animation can be perceived as unnatural because developers often do not know how to pause or present the animations in a life-like manner. In addition, they can fail for deeper cognitive reasons, as individual's chunk continuous events that take place over time by processing animated events as sequences of discrete steps (Zacks, Tversky, and Iyer, 2001). For instance, Tversky et al state that animations should use time in ways that reflect expert understanding of processes in order to prevent them failing the Principle of Apprehension. They should start, stop, slow down, and speed up. Individuals refer back to static images to reflect and recheck information, therefore time and space in animations need to be altered to incorporate zooming, enlargement, change in perspective and involve spatial variations, which are cued by abrupt or continuous temporal changes.

Animations also fail by focusing too much on change. For instance, individuals know that a wall will be built brick by brick if they can see the beginning of the construction. It doesn't need to be demonstrated, as information is naturally inferred by the user in some instances. The key factor is to know when to manipulate the scenarios via textural information or even auditory stimuli, as explanations and narrative voice-overs have been demonstrated to augment communication and learning through visualization (Mayer & Sims, 1997).

To date, there is little research which measures the effectiveness of visualisations directly to costs of a completed building. The current focus appears to be the inclusion of VR in the building process with research into the optimal use of the technology largely being ignored (Westerdahl et al, 2006). It has been argued that mental models are quite different from actual models, it is evident future VR capabilities require tight coupling for efficiency and flexibility for change in order to achieve the much desired seamless integration. Much investigation is needed to develop a process that fine-tunes the representations and improves communicative efficacy. Research has merely highlighted many unknowns; visualizations and animations can be produced and tested for performance and preference amongst a variety of users. When there is convergence, that is, when the same visualizations exist in all tasks, design principles can be identified. Cognitive design principles need to be interwoven with architectural science and appear seamless in research, not as a separate school of 'after-thought.'

Obviously, extensive consideration must be also given to architectural conventions, striking a balance between three basic concepts identified; abstraction, accuracy & realism (Pietsch, 2000; Bates-Brkljac, 2009). This is especially relevant with respect to ethical principles, designs can be compared to creations post-hoc and, in an ever increasing litigious society, a fine balance is required between realism and visualisation. The 'rules' will need to be coherently explained to the potential users and observers. Once the framework is fully developed, there is great potential to achieve a coherent and tacit accord in the industry that visualization offers a superior system for organizing, researching, simulating, testing, generating and communicating complex data.

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