

iconic forms, form analysis data and daylighting data; it is fairly easy to develop different forms each intended to reach a different architectural trend and compare between them using the parametric tools that generated each.

## **28. Spatial Solutions and Solution Spaces: The use of Virtual and Augmented Reality in Design Exploration**

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The recent wave of Virtual and Augmented Reality (VAR) technologies has coincided with new technologies for processing, analyzing and evaluating large amounts of data. In general, the purpose of Data Visualization is to enable the user to discover and understand patterns in data. Good visualizations present large amounts of data in a way that is easily understood, and good interactive visualizations promote intuitive means of exploring relationships. Over the past few years many researchers have looked into the development of immersive Virtual Environment platforms for Big Data visualization, such as, iViz (Donalek et al, 2014) and the work carried out by Masters of Pie and Lumacode for the Big Data VR Challenge in 2016 (Lumapie, 2016). Filtering, combination and scaling have all been identified elsewhere as important interactive techniques used in contemporary data visualization (Olshannikova et al, 2015). Of these, scaling may be the most familiar to architects: for centuries, designers have attempted to experience architectural space in different scales simultaneously, by using models at different scales (Yaneva, 2005), and by employing various drawing techniques to achieve an embodied perception of the designed space. With the use of VAR technologies this becomes easier than ever. At the same time, designers increasingly must understand not just the experience of a design proposal but also the data associated with it.

To experience data as part of a design process emphasizes that architecture addresses wicked problems (Buchanan, 1992; Rittle and Webber, 1973) requiring negotiation between various disciplines and performance objectives. Critical criteria including aesthetics and contextual suitability further complicate design process because of their resistance to quantitative and objective measurement. Reaching a resolution to these myriad constraints and conflicts is a learning process through which numerous potential schemes are explored. The application of computers, especially through parametric modelling and optimization algorithms, significantly facilitates this process by generating and analyzing a large number of design alternatives (Woodbury 2010 and Turrin et al, 2011). The trade-off for this power is the need for well-defined parameters to generate schemes and the need for strictly applied criteria to evaluate these schemes. Brander et al. (2014) identify opportunities to use design optimization not to find the best performing solution, but to gain understanding about the design space, which is often used as the starting point for design exploration. Since the candidate points are equivalent in that each represents an optimal solution according to particular combinations of objectives, a selection and evaluation phase is required in order to extract useful information (Shir et al., 2013). Typical approaches to visualizing the space of multiple potential solutions

(Chaszar et al., 2016; Sileryte et al., 2016; Ashour and Kolarevic, 2015) plot candidates as isomorphic points embedded in a low-dimensional space, which makes it difficult to develop an intuitive approach to navigating this solution space. Recently there has been much effort applied to create better design space exploration software. Nevertheless the full potential to efficiently generate and meticulously examine candidate solutions from the perspective of multiple disciplines has not been fully realized (Flager and Haymerker, 2007). Maile et. al (2007) attribute this to poor user-experience in this class of tools.

We address these issues by considering some of the opportunities and challenges of using VAR technology to simultaneously experience spatial and non-spatial data related to architectural design. We do this by reflecting on application of VAR technologies in the design process in a large architectural practice. Two key approaches are identified:

- 1) a superimposition of data in embodied interaction with design schemes
- 2) a spatial experience of higher dimensional data related to design schemes, facilitating the designer in navigating the solution space or morphospace.

We discuss the merits of each of these approaches with reference to application in the design of tall buildings. The effectiveness of multi-objective optimization (Gerber and Lin, 2014) and design decision support systems (Singhaputtangkul, Natee, et al., 2013) in the design of tall buildings have been demonstrated elsewhere. Building on these precedents we demonstrate the potential of immersive interaction in navigating and understanding individual design options and groups of candidate solutions.

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## 29. Archi-lab + Citi-lab

Bringing together digital information, ideas and technologies for interactive 'real-time' visualisation that can help create better places

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Fusing the virtual world of gaming software with 'hands-on' real-time simulation or augmented reality in urban and architectural environments is a game-changer for the development industry. Citi-Lab and Archi-Lab software has been created to provide design professions, developer agencies and assessing authorities with a higher level of performance and accuracy in the development and assessment of project designs within their context during the critical early stages of project implementation.

The software enhancement can generate demonstrable or measurable outcomes within the CAD modelling space, and with the capacity for feedback loops to display immediate responses, these services can enable much more effective use of digital data in early stages of urban design and architectural environments. Working with a base CAD model, attributes given to elements and spaces can be assessed with algorithms to provide