

# ARTIFICIAL INTELLIGENCE FOR PREDICTIVE AND EVIDENCE BASED ARCHITECTURE DESIGN

*Integrating Spatial Reasoning, Cognitive Vision, and Eye-Tracking  
for the Analysis of Embodied Visuo-Locomotive Experience in the Built Environment*

**Mehul Bhatt, Jakob Suchan, Carl Schultz, Vasiliki Kondyli, Saurabh Goyal**

The DesignSpace Group., and University of Bremen, Germany. [www.design-space.org](http://www.design-space.org)

## The Architectural DesignSpace

Architects concerned with designing built environments (e.g., hospital or an airport) need to “anticipate” and “ensure” that people-centered design objectives are fulfilled, e.g., people should (not) get lost, the environment should fulfil universal design criteria for diverse user groups and situations, e.g., disabilities, geriatric care, emergencies. Toward this, designers and architects need access to assistive technologies —**people-centred design systems**— that manifest a basic understanding of human behaviour in spatial environments, in particular, aspects pertaining to “*visuo-spatial perception and cognition*”, and creative and expertise-driven “visuo-spatial thinking”. Our research on people-centered spatial design categorically addresses the question:

*How can human cognitive modalities constitute the foundational building blocks of design systems, education, discourse, and the professional practice of spatial design for architecture?*

We summarise basic research questions addressed, methodology adopted, and deliverables produced in our research on the development of computational cognitive systems and assistive technologies aimed at architectural practice & pedagogy. Key highlights of our work from the viewpoint of the areas of artificial intelligence, visuo-spatial cognition, and human-computer interaction research are presented.

## Artificial Intelligence and Design: Visuo-Spatial Cognition is Central

The basic proposition of our research on developing computational cognitive systems and assistive technology for people-centered architecture design is that:

**next-generation design systems, frameworks, assistive tools, educational discourse, and design practices** need to be explicitly founded on the cognitive modalities of *human perception, attention, action, dynamics, environmental affordance and user experience, and design conception & semantics*.

We construe human visual perception and navigation — for both predictive as well as observed / empirical analysis purposes— in built-up environments as:

Copyright © 2015, Association for the Advancement of Artificial Intelligence ([www.aaai.org](http://www.aaai.org)). All rights reserved.

**dynamic visuo-locomotive narrative experience** —*i.e., involving movement and exploration— driven by situation-dependent goals, guided by visual aids such as signage and landmarks, and influenced by environmental (e.g., presence of other people, time of day, lighting) and personal factors (e.g., age, physical attributes).*

The prediction of individual or group level visuo-locomotive narrative experience (at the scale of everyday human perception and thinking) during preliminary design, or its observed analysis in a real-world setting by experimental means has been a dominant line of thought in our research.

## Predictive Analysis for Not-Yet-Built Designs

Our research has addressed the representation of *space* from a formal modelling and computational viewpoint, *i.e., space*, as it is interpreted within the disciplines of artificial intelligence and knowledge representation (KR) in general, and logic-based geometric and qualitative spatial representation and reasoning, applied ontology & formal semantics, and spatial computing for design in particular. Our key research methodology and deliverables have been along three dimensions (C1 – C3):

**C1. Conception.** how can the future evolution of (architectural) design computing bring notions of design semantics, structure, function, and people-centred design to the fore at an ontological, representational and computational level?

**C2. Computing.** What is the role of specialized visuo-spatial abstractions, and commonsense spatial reasoning within the broader realm of design computing, spatial design assistance, and tools for design learning and education?

**C3. Communication.** What is the nature and form of the analytical feedback that designers and planners expect during the early design conception and iterative refinement phase? What are the implications of this from the viewpoint of human-computer collaboration and interaction design aspects of design systems?

The applied perspectives offered by our “*AI for design computing*” agenda have resulted in the *declarative spatial reasoning* paradigm within a KR context. Particularly, methods for **commonsense spatial reasoning** with constraint logic programming [1] and answer set programming [9] have been developed.



Figure 1: An eye-tracking experiment involving a wayfinding task at the New Parkland Hospital in Dallas, Texas (USA). Visualisation includes gaze-points, as well as automated signage extraction from ego-centric video capture.



Figure 2: Computationally generated immersive reality experience based on multi-modal perceptual data and its high-level grounding and analysis; primarily includes integration of fixation analysis from eye-tracking data, automated signage extraction from video, and pre-designed 3D building model based on the Building Information Model (BIM) standard.

## Evidence Based Post-Occupancy Analysis

The evidence-based analysis of people's navigation and wayfinding behaviour in large-scale built-up environments encompasses the measurement and qualitative analysis of a range of aspects including people's visual perception in new and familiar surroundings, their decision-making procedures and intentions, the affordances of the environment itself, etc.

**Cognitive Vision & Eye-Tracking.** We employ a range of sensors for measuring the embodied visuo-locomotive experience of building users: *eye-tracking*, *egocentric gaze analysis* (from video), *external camera based visual analysis* to interpret fine-grained behaviour (e.g., stopping, looking around, interacting with other people), and also manual observations made by human experimenters. In this framework, abstract regions like the *visibility space*, *regions of attention*, *eye movement clusters*, are treated as **first class visuo-spatial objects** that can be used for interpreting the visual experience of subjects in a high-level qualitative manner. Observations are processed, analysed, and integrated in a holistic model of visuo-locomotive narrative experience at the individual and group level.

**Building Morphology.** Our model also combines embodied visual perception analysis with analysis of the structure and layout of the environment (e.g., topology, routes, iso-vists) computed from available 3D models of the building. The final integrated analysis of the wayfinding experience is such that individual and aggregate experiences can also be presented in a virtual and immersive reality environment.

## Visuo-Spatial Cognition, and Architectural Pedagogy, Learning, and Practice

Our construction of embodied visuo-locomotive narrative experience as multi-modal sensorimotor analysis centralises the role and influence of perceptual & locomotive characteristics and morphological features of the built environment into the discourse on design thinking, and evidence-based design research, e.g., for domains such as hospital, airport, museum design. Developed tools have been applied for pre-construction design & post-occupancy analysis, and also in

certified continued education programs [4] aimed at introducing visuo-spatial cognition into architectural curricula.

## References

- [1] M. Bhatt, J. H. Lee, and C. Schultz. CLP(QS): A declarative spatial reasoning framework. In *Spatial Information Theory - COSIT 2011, Belfast, ME, USA.*, volume 6899 of LNCS, pages 210–230. Springer, 2011.
- [2] M. Bhatt, J. Hois, and O. Kutz. Ontological modelling of form and function for architectural design. *Applied Ontology*, 7(3): 233–267, 2012.
- [3] M. Bhatt, C. Schultz, and M. Huang. The shape of empty space: Human-centred cognitive foundations in computing for spatial design. In *IEEE Symposium on Visual Languages and Human-Centric Computing, VL/HCC 2012, Austria*, pages 33–40, 2012.
- [4] M. Bhatt, C. Schultz, L. McGilberry, B. Agosta, and G. English. Universal Design and the Built Environment: Cognitive Technologies and Educational Discourse for People-Centered Spatial Thinking & Architecture Design. In *Accredited Research Intensives - EDRA45.*, New Orleans, 2014. URL [www.design-space.org/edra45](http://www.design-space.org/edra45).
- [5] M. Bhatt, C. Schultz, and M. Thosar. Computing narratives of cognitive user experience for building design analysis: KR for industry scale computer-aided architecture design. In *Principles of Knowledge Representation and Reasoning - KR 2014, Vienna, Austria*. AAAI Press, 2014.
- [6] C. Schultz and M. Bhatt. Multimodal spatial data access for architecture design assistance. *AI EDAM*, 26(2):177–203, 2012.
- [7] J. Suchan, M. Bhatt, and P. E. Santos. Perceptual narratives of space and motion for semantic interpretation of visual data. In *Computer Vision - ECCV 2014 Workshops - Zurich, Switzerland*, volume 8926 of LNCS, pages 339–354. Springer, 2014.
- [8] J. Suchan, M. Bhatt, and H. Jhavar. Talking about the moving image: A declarative model for image schema based embodied perception grounding and language generation. *CoRR*, abs/1508.03276, 2015.
- [9] P. A. Walega, M. Bhatt, and C. Schultz. ASPMT(QS): non-monotonic spatial reasoning with answer set programming modulo theories. In *Logic Programming and Nonmonotonic Reasoning - LPNMR 2015, Lexington, KY, USA. 2015.*, volume 9345 of LNCS, pages 488–501, 2015.