REPRESENTING CO-URBAN DESIGN REALITIES

Evaluating the emergent significance
of spatial computing on
collaborative practice

Doctoral Thesis

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On the title: ‘Representing Realities’

Representation as audio-visual, a digital reflection (Gül *et al.*, 2013)

Being Representative = Participatory (Arnstein, 1969)

Representation is a clone, aligning to existing norms, not creation (Deleuze and Guattari, 1994)

We are limited in our observation of reality, but yet are agents of real change (Bhaskar, 2008)

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Declaration

I, Lucas Hughes*, declare that the work in this thesis was carried out in accordance with the regulations of The University of Sheffield, and is an original piece of research, except where referenced (*[James] Lucas Hughes: 190203865)

Declaration of Competing Interest - the author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this research

Dedicated to:

Standing: Participating Staff and Students at the College of Architecture: Birmingham City University
Shoulders: Alexia 1611; King Sol | Lord Seb
Giants: OftenMum, N.o.r.m.a.n, Super Oma, et alia.

ABSTRACT

Spatial computing, *e.g. AR-VR – connecting to wider computing,* remains on the periphery of standard use in Urban Design practice and academia, for example from socioeconomics, planning, and architecture. This is despite great developments in mainstream accessibility and capability over the last decade, as well as a legacy of discussion on areas of potential revolutionary benefits to the collaborative urban design process. This study aims to better understand the practical scope of its current and future potential, including the underlying social contextual influences and strategic requirements. This research is situated within the complex, changeable conditions of Urban Design, which are concerned with unique, place-based conditions and involve an interplay of technical, cognitive, and social processes.

Methods: Participants' perceptions and actions were captured through a sequence of interviews/focus groups with urban design practitioners, software developers, as well as live design testing of AR and VR by students and key practice stakeholders, as real-world connected events and design project case studies. The case studies acted as contextual containers, with data captured from a suite of mixed methods: audio-video, transcript, images, including analysis of external and headset video. The participants came from a range of backgrounds, disciplines, and levels of urban design experience and ability, including professionals and students, and non-design stakeholders, including members of the public. The approach of triangulating different data types captured from non-laboratory conditions enables evaluation across multiple analytical viewpoints, shedding light on some key social mechanisms that influence collaborative processes and products.

Results/Future Work - This study adds to an emerging, holistic perspective on how spatial computing is and might increasingly impact the practical and social dimensions of collaborative urban design as a process. This includes identifying key thematic and specific gaps in theory and capability, and defining their size, scope, and areas of potential development. This study argues that there is a need to frame areas for technical development towards appropriate urban design solutions, with greater consideration of the social context for design, including collaborative processes, specific interfaces, and interactive requirements. Simultaneously, it highlights that various ongoing technical issues present barriers that negatively influence social confidence and uptake, thus limiting our ability to conceptually push further toward aligned solutions. In conclusion, this study evaluates the key areas for further research that are needed to allow spatial computing to fulfil the much-claimed potential.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

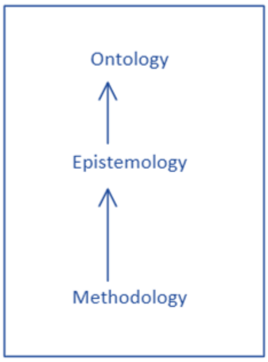
URBAN DESIGN – design of urban areas, an inherently strategic, transdisciplinary subject/activity, both of an urban context and an aim / set of evolving approaches

- Urban (context) – a distinctly human environment/ecology, a physical entity and cultural construct
- Design – a process of imagining, communication and delivering of The Urban Design products / outputs (e.g. design drawings, planning reports, ultimately, the created design)
- Design process: common stages and approaches involved in design, with general and specific approaches by discipline
- Urban Design process – strategic, framework design and conceptual design vision
- Built Environment: *Architecture, Landscape Architecture, Civil Engineering, Planning: and sub-disciplines, such as Transport planning*
- Development / Redevelopment – process of physical creation and implementation of urban design, places, / physical adaptation of previously established urban places, implying substantial change

SPATIAL COMPUTING: All aspects of computing can be integrated into spatial perception. A broader, all-encompassing, non-specific–as in addition to Extended Reality (XR) technology–a conceptual integration and relationship to wider digital influence such as Artificial Intelligence, Smart City data, etc.

- Extended Reality (XR) is a specific grouping of technologies which digitally overlay perception of reality, as variable amounts of augmented (AR) and Mixed Reality (MR) elements, to full immersion in total Virtual Reality (VR).
- Virtual Reality, VR - complete audio-visual sensory immersion in a virtual space
- Augmented Reality, AR - minor to major overlay of audio-visual elements overlaid on top of real space
- Mixed Reality, MR – alternative, somewhat competing terminology, stated by some as augmented reality with: Occlusion - extent of ability to accurately simulate the visual placement of virtual objects behind real objects
- Reality / or virtually Real - The Real World as 3D space that we are situated in - as we understand it to be an actual / real place, potentially merged with digital elements
- Hybrid Reality - used similarly/alternatively to extended reality, but with conceptual focus on the integration/blurring of boundaries between real and virtual space, and objects
- Immersion - extent of a person being emotionally absorbed/involved in an experience
- Presence - extent of a person feeling like they are actually 'present' in a space/place
- Virtual / Simulation, Digital Twin - a copy, clone of real thing (object, space or experience)
- Virtual World - a completely digital spatial world, aligns to virtual reality, also 3d modelling more generally (including computer games and online shared social spaces)
- Realism – the 'level of', as extent to which an artificial, virtual space or object feels like our perception of actual reality
- Hyper Reality – a deliberate emphasis on audio-visual effects that are beyond normal human experience in the real world, deliberately not-real, enhanced, a 'hyped-up' version, also relating to theory of hyperreality, imagined places that become normalised – as conceptualised by Baudrillard (Wolny, 2017)

PHILOSOPHY



- Epistemology – our Knowledge of Reality, 'how do we know' *(and/or, on the rationale/justification for a certain argument)* - *'how can I know reality?'*
- Foundational Theory:
  - Positivism - *that Reality is factually based on the empirical*
    - Rationalism - *that Knowledge comes from reason, over emotion, or belief*
    - Empiricism - *that Knowledge should derive from real observations*
- Realism - that scientifically derived theories are 'approximately true'
- Interpretivism - that facts are derived and understood via human interpretation/perception
- Relativism - that truth and morality are relative (to context/ lens)
  - Post-Positivism – *our understanding of Reality is based on interpretation of the empirical*
- Ontology – 'of being' or reality – on what is reality?
- Critical Realism – an Ontological reality exists independently of our knowledge about it, Reality is not fully observable. Our observations are always limited by position and method and are fall- and theory-dependent. However, a closer approximation can be obtained by seeking multiple perspectives and ongoing research iterations. (Bhaskar, 2008)

METHODOLOGY

- Empirical - *verifiable data as observed, or - experienced (Positivist, or - Interpretivist)*
- Causality - causes for phenomena = cause and effect
- Critical Realist – (Raduescu and Vessey, 2008)
  - Causal Mechanisms - the underlying system (mechanics) that enables a cause to have an effect
    - Tendencies, Powers (Liabilities) – *capacity* for certain individual behavior within social context, e.g. 'power dynamics'
      - Liabilities, negative power - inherent risks within a system
- Assemblage theory – structure of real-world social organisation are emergent and only temporally fixed, as a changeable network, a cluster along a dynamic rhizomic structure ('of becoming, not being' (Dovey, 2023a)
- Design
  - Capacities – current and potential capability of a person, or group to collaborate certain actions
  - Affordances –
    - Physical design affords certain cognitive actions, e.g. understanding what a door handle is/does
    - Social situational norms, afford certain actions

- Grounded – theory should be derived from analysis of data, not testing a pre-determined hypothesis, as being emergent from empirical (Strauss and Corbin, 1991; Charmaz, 2001)
- Analytic Inference: (Meyer and Lunnay, 2013)
    - Induction – observation
        - Bracketing - process of setting aside personal experiences, biases, preconceptions of the research topic
- Deduction - based on accepted facts, proving what 'must be' – data compared an existing theory framework
- 'a priori' - based on theoretical deduction, rather than empirical observation
    - Abduction – open analysis, comparing data and theory – *how something <u>might</u> be* (Wiltshire and Ronkainen, 2021)
    - Retroduction – estimate, iterative hypothesis; emergent from observation (Belfrage and Hauf, 2017)
    - Reflexivity - reflection on influence of beliefs and practices on research (Alvesson and Sköldberg, 2009)

SUMMARY OF CHAPTERS

Chapter 1	Introduction Extended summary introducing and holistic overview of aim and approach
Chapter 2	Contextual and Theoretical Framework Context/ key debates supporting the need for a collaborative, 'Co'-Urban Design and an overview of spatial computing.
Chapter 3	Philosophical Basis Philosophical underpinning of the research, position.
Chapter 4	Methodology Evaluative approach triangulated from a suite of methods and overall timeline, participant and context types
Chapter 5	'State of the Art' - spatial computing for Co.Urban Design Critical review of contemporary research papers on emergent potentials and considerations for SC Co.UD, identifying key gaps / further research.
Chapter 6	Results: Interviews and Focus Groups Primary data, key summary of transcripts
Chapter 7	Results: Narrative and Analysis of Events Primary data, key summary of mixed data within case
Chapter 8	Discussion: Themes of a Spatial Future Intepretation of key themes with relationship to existing knowledge
Chapter 9	Conclusion Summary and implications of the research. Gaps, limitations: areas for further research. Future questions
Chapter 10	References and Appendix Illustrative examples of method and/or supporting primary information

1 INTRODUCTION

This chapter provides a holistic overview of this study. Tying together the rationale for this research as problem-opportunity, key topics, and sub-themes, as well as the research structure and direction, its *aim*, and the alignment of *research questions* with *objectives*. It asks the research question: *How might Collaborative Urban Design (Co-UD) influence and be influenced by the incorporation of spatial computing (SC) methods in real-world practice?*

This is approached through action and reflective research of practice-aligned cases in the UK.

1.1 Overview - Problem, Process and Product

The Potential for Change

While the efficiency and capabilities of Urban Design production have been revolutionised by digital technologies such as screen-based pcs, laptops, and mobile devices, they also present an experience that can increase abstraction and separation from the physical world in which we interact. This places the user's focus on a personal screen (2D space, view) which emphasises users own perspective only, and therefore reinforces individual working process. This can present various barriers to spatial design and collaborative working processes. These two-dimensional interfaces commonly pose a distraction and abstraction that reduces physical interactions and can in-turn, encourage 'silo' processes and mentalities.

spatial computing is developing to (re-)integrate processes that have become dominated by digital technologies, (back) into our daily spatial realm and default way of communication, that is, placing digital objects and spaces, for design interaction within our real, physical perspective experience. In this way, spatial computing presents the opportunity for design to become closer to real construction, that is, building, crafting, and making changes to the spatial-physical world in ways that are seen, felt, and understood immediately by others. It might also act in ways like a traditional hand drawn design studio, where interactions between collaborators might be more fluid and immediate. In addition, there are assorted options for blending multiple digital and physical spaces (e.g. applied to 'remote working').

spatial computing has the potential to return to the long-standing benefits of physically present work for designers, which is more akin to precomputing processes, while also transcending physical constraints where desirable. For example, digital overlays enable bypassing the constraints of budgets and physics (where appropriate) that are present in real-world design/construction. This presents opportunities for infinite test spaces/objects, with copies, animations, etc., with the benefits of quick ideation, production efficiency, and extended scope.

Silos, which are barriers to traditional computing, pose a problem for collaboration during the design process. Most significantly, they can separate out and present additional steps, reinforcing barriers between those who have knowledge/skills and those who do not, owing to additional gaps in the skill set and focusing on the siloed processes of working. In a lesser but still significant way, this also reinforces barriers between different areas of design, including those who may use different processes, languages, and have different aims. In both cases, as a planning and design process, this relates to and presents itself as the creation and/or reinforcement of sociopolitical barriers.

With relation to the emerging capabilities of spatial technologies, there has been limited exploration or testing of established methods or frameworks. For the methods explored, there is still much scope for further nuance and extension of verification testing. There has been limited testing in live, collaborative contexts, such as highly variable, real-world applications.

1.2 Research Aims, Questions, Objectives

Aims and Objectives

This study iterates a framework for reflecting on current directions. Within this context, this study explored future areas of potential for the development of spatial computing to support various multilayered requirements of Urban Design as a *field* (and by that definition, UD's various related *disciplines*–for example, Planning, Architecture/Landscape Architecture, and related specialisms). This study presents the argument that technology hardware is only as useful as its software application in specific areas of action, which, in the case of urban design (UD), is currently very limited in terms of depth of consideration and application. This is the case not only in specific applications but also in a more holistic integration of features that relate both to conceptual and theoretical understanding of what might be possible. More importantly, what is desirable?'

In the context of a very limited selection of spatial computing software that can be applied or adapted for use in the UD process, let alone one that is theoretically optimised for the many layers and areas that might be of potential use and benefit the urban design process. This study aims to contribute conceptually to future roadmaps for spatial computing software for urban design. Building on prior studies in a range of transdisciplinary areas. This study aims to present a mix of practical and conceptual improvements to collaborative urban design as a process of using spatial computing in terms of current actions that might be taken. In addition, it aims to show areas that could and should be optimised in the future, as we move beyond the current limitations. It suggests ways in which current and future spatial computing systems are starting and might further impact contemporary urban design as a practice that (at least) aims to be collaborative and participatory. A particular focus within this will be on the potential influence that changes brought by spatial computing could have on the socio-political mechanisms that affect the relationship between and processes (i.e. participatory collaboration). It also explores, develops, and tests a research methodology that supports these strategic levels of evaluation by recording multi-perspective, mixed-media, and transdisciplinary inputs.

Research Aims – an investigative study

i. Investigate the reciprocal relationship between Collaborative Urban Design and spatial computing methods related to areas of real-world practice

ii. Analyse how spatial computing might influence the effectiveness of Collaborative Urban Design, currently and in the future

Research Questions and aligned Objectives

Each question below (1-3) explores a key aspect of the main aims, presented in alignment with objectives (a-c), as a breakdown of the approach to answering questions. Note. All objectives relate specifically to spatial computing for Collaborative Urban Design ('SC-CoUD').

1) How might spatial computing capabilities align with collaborative Urban Design activities?
   a) Assess current technical and conceptual capabilities of SC types
   b) Assess functional, environmental and emotional affordances offered by spatial computing

2) How might spatial computing influence decision-making, collaborative working, and participation in Co-Urban Design?
   a) Assess impacts on effectiveness of design process and activities, in terms of scope, depth and focus
   b) Explore the implementation of SC with relation to individual and collaborative capacities within the context of social and organisational structures

3) How can spatial computing be technically and conceptually advanced to further the needs of Co-Urban Design?
   a) Advance understanding of socio-organisational, procedural and ethical implications central to urban design professionals and stakeholders' areas of practice: stages, contexts, transdisciplinary working
   b) Conceptualise future applications, based on assessment of current gaps and areas of potential

The questions are explored in *real-world events: practice aligned, changeable, temporal, physical, and social contexts; and design aims, influenced by project length, complexity, stage(s), and cultural-organizational situation [see Chapter 4 Methodology].*

1.3 Thematic Basis, Content and Structure

This paper is presented as an analytical narrative (Silverman, 2017) in the form of a qualitative record that presents key concepts, followed by an evaluation of these concepts in light of the findings, in addition to understanding the research problem. This project has three core themes.

1. Co-Design (Co.) - transdisciplinary, multi-perspective collaboration, towards' better:
2. Urban Design (UD): The design of our complex human ecology using
3. Spatial Computing (SC) has the potential to use extended reality technologies (such as Augmented, Virtual Reality) alongside wider computing advances to simulate multidimensional effects on our perception of reality, including effects that are spatially immersive, divergent, and interactive.

Converging the inherent complexity of the above themes, this study considered a theoretical framework based on social perceptions of reality. This study defined urban design as various physical and social layers which can be spatially formatted using computer simulations. This ties to the ideas of *assemblage theory*, which exist within a diverse multiplicity involving clusters of social and physical institutions and the networked reality of flexible, emergent structures (Morgan, 2003; Dovey and Pafka, 2014), that is, groups and networks of:

a) Stakeholders' views, and of
b) Spatial computing approaches, products, systems and designs
c) Urban design is a product of subjective societal requirements and objective physical conditions.
d) Acknowledging and embracing alignments and/or misalignments between the varying influences of a), b), c)

Research Process

Data will be collected from a range of participants with live and/or reflective responses in urban design-related contexts (projects and studies). This will directly connect and test theoretical exploration with the practical actions of real-world urban design.

This will include perspectives from diverse participant backgrounds, various urban design-related areas of practice (including professionals and students), members of the public and other stakeholders, those directly developing spatial computing for UD, and of different ages and demographic backgrounds. It collects data that aims to illuminate co-design actions and processes in relation to specific live contexts, including the recording of spoken discussions, visual design outputs, and observation of collaborative actions. Since this is expected to be of experimental and reflective nature, the aim was to capture unexpected areas of interest. Overall, an adaptive/reflexive approach to data collection aligns with the nature of the study design and emergent spatial communication. The data will be evaluated from the perspective of urban design and collaborative work, rather than focusing on current or future technological limitations. However, these limitations will be evaluated to gain a ground understanding within the context of the current feasibility and timelines for future applications.

The research product works towards an emergent, framework that hopes to shed light on the relationship between spatial computing methods and an analysis of their accessibility within a Co-Urban Design. This includes the extent of the current feasibility and/or emergent potential. It also considers how these methods may be integrated with or replace the currently established methods. This is considered within practical co-design scenarios, and as the technological capability of spatial computing develops, the key principles of practical and conceptual guidance are established. In Evaluation of these outputs details the potential of practical and social influences that spatial computing methods might start to present for Urban Design.

1.4 Spatial computing for collaborative Urban Design?

Co. Urban Design

Urban design here is understood as an 'umbrella profession, or field', interested in strategic, holistic design considerations, especially in the early conceptual phases of urban environment design (*As expanded in Chapter 3 contextual review). Thus, it is greatly influenced by politics, planning, policy, and implementation as a framework approach to design which is typically actioned through further detailed design and construction phases. It is typically handled by the following actors: Architects, Landscape Architects, Engineers, building contractors and those involved post-construction management and place stewardship (Mcglynn and Murrain, 1994; Knox, 2020, pp. 2–3; Larkham and Conzen, 2021, pp. 9–11) .

In the complex multiplicity of social and physical conditions that define any given urban *place* and where it seems certain that no one person can know everything, the ideal scenario is to gain as much stakeholder insight as possible. Debates within the theory and practice of Urban Design regularly discuss the need for a greater scope and variety of experts, stakeholders, and public influence (Jayne and Ward, 1996; Lang, 2005). The idealised benefits of such collaborative and participatory practice cover many layers and dimensions, but simplified for the purpose of this introduction, provide the opportunity for a 'more than the sum of their parts' *Collaborative Advantage* to the design process (Huxham and Vangen, 2000).

However, gaining consistent, practical value from such participatory collaborations is often much easier said than done. Like the urban context, the social nature of collaborative processes can be highly variable because they are influenced by multiple variable factors. One of the most significant influences on these factors relates to the communication methods and formats used, as well as the facilitative interface that organises these formats. In this context, communicative gaps can emphasise misunderstandings and unconscious biases, which might affect the relationship between collaborators of different backgrounds, experiences, knowledge, and skills. These gaps are often the greatest where processes seek to involve the wider public alongside planning and design practitioners (Nelson and Bobbins, 2017).

Owing to the spatial-environmental focus of Urban Design and related design disciplines (for example, Architecture, Landscape Architecture), there is great emphasis on visual communication as a method for communicating the experience of a certain *place*. Most visual methods rely on degrees of abstraction from the reality they represent, typically either as conceptual (including diagrammatic) or technical (including 'realistic') representations of the three-dimensional reality they represent/propose. Owing to a lack of experience or training, the level of understanding of these abstract, non-intuitive methods, such as reading a 2D plan (map), can vary, compounding other issues of collaborative cohesion.

Spatial Computing?

As a broad umbrella term, spatial computing (SC) encompasses a spectrum of *Extended Reality* technologies (XR: Augmented-Mixed-Virtual reality), with the addition of connection to other areas of computing, both in a general sense and with specific combinations that show promise, for example, combining XR with Artificial intelligence (Ai), Geographic Information Systems (GiS), Building Information Modelling (BIM), big data/smart city infrastructure, Internet of Things (IoT), etc.

The fundamental capability along the XR spectrum is the presentation of digital information as a perceptively spatial experience for the user, that is, of 3D elements joining the real world (as an overlay), or the user being 'in' the 3D world (immersed). This can provide a greater and more intuitive scope and capability of understanding, and therefore, the potential for greater input from a wider range of transdisciplinary stakeholders.

In research and practice, spatial computing is increasingly demonstrating ways to close communication gaps through the enhancement, addition, or replacement of established design communication capabilities. The two major formats of XR are as follows:

1. *Augmented Reality and Mixed Reality (AR/MR) - Augmenting 3D digital design data into real 3D space*
2. *Virtual Reality (VR) - Total immersion of users in a virtual representation of physical 3D space*

(Portman, Natapov and Fisher-Gewirtzman, 2015; Fisher-Gewirtzman *et al.*, 2017)

Spatial computing (SC) has seen a rapid shift from being highly inaccessible and specialist to being much more accessible and non-specialist (Lange, 2011). Where formerly there was a need for lab conditions, with expensive, bespoke equipment and advanced technical knowledge, recent mobile and head-mounted spatial computing systems are available as mass-produced products with quickly downloadable applications (for example, VR on Meta Quest, AR on Apple iPad). They are significantly cheaper to implement, have integrated operating systems, and use ergonomic control interfaces that are increasingly standardised and much more intuitive (Fonseca *et al.*, 2014; Fonseca Escudero *et al.*, 2017).

However, despite much discussion of revolutionary capabilities and significant technological advances towards accessibility, which has been echoed by increased industry knowledge and experience (Noghabaei *et al.*, 2020), the use of spatial computing across all stages of the built environment process is still very limited and more so for the early stages of urban design conceptualisation. For the majority of practices and academic teaching methods in areas related to Urban Design, spatial computing uptake is applied in niche use cases, with AR showing even less practice adoption than VR

Is this due to reluctance to change? Are there significant gaps in technical capabilities? Alternatively, is there perhaps something more fundamental that needs to be addressed? The reasons for this remain unclear and underexplored, particularly in real-world design contexts.

1.5 Research Contribution - Overview

Despite a body of emergent knowledge, there are still many gaps related to the use of spatial computing in a variety of areas that are applicable to Urban Design (and its affiliated disciplines) (Portman, Natapov and Fisher-Gewirtzman, 2015; Çöltekin *et al.*, 2020; Ataman and Tuncer, 2022), both as a broad process and as investigated here for co-design-specific stages and processes. The current lack of a holistic methodological overview is particularly pertinent, especially when applied to complex real-world places and project processes (Araabi, Carmona and Foroughmand Araabi, 2017), which are always influenced by the contextual complexities of local physical conditions and fluctuating sociopolitical forces (Lang, 2005; DeLanda, 2019).

A review of the literature within the emergent context of spatial computing has shown that studies (and technological developments) have focused on specific technological or practical capability experiments and verification. In this emergent area with large gaps, the primary aim has been to produce software or hardware capabilities, often in ways that replicate or enhance established Urban Design methods with specific technical benefits. While certainly valuable as a specific proof-of-concept, there can be noted in reviewing the spectrum of papers a common tendency towards speculation of broader usefulness in the conclusions. The claims of 'benefits' to participatory, or collaborative working need to be explored further in real contexts (see Chapter 3.4, section 'Claims to Panacea'). There are also many more areas to be specified to better understand how, where, and what range of benefits and limitations exist, or how, where, and when they might be applied. This may apply across a complex timeline of variable processes and places that comprise urban design studies (Carmona, 2014; Black and Sonbli, 2019).

As spatial computing becomes more accessible to non-specialist users, it is becoming increasingly important to test these new capabilities under real-world conditions that relate to real end-user experiences in practice and public processes (Gill and Lange, 2015). When evaluating spatial computing considering these goals, it is also important to understand new capabilities in comparison to the broad suite of highly established and practice-grained methods (Gil, Duarte and Syntax, 2008), as specific benefits with significant drawbacks do not necessarily provide holistic benefits.

Related to these practical uncertainties, there is theoretical uncertainty regarding the potentially disruptive impact of immersive modes on the design process (Koutsabasis *et al.*, 2012). This is not only in terms of what <u>can</u> be done, but also what <u>*should*</u> be done, both from practical and social-ethical perspectives. Thus, there is a need to gain knowledge on how spatial computing may affect urban design in a philosophical sense and how we may engage in more aligned development.

To understand the influence of spatial computing on Co-Urban Design, it is pertinent to add deeper evaluation by trying to find the social reasons for certain outcomes [that is, see methodology chapter 4]:

- To show explanations for <u>why</u> certain perceptions are felt and actions occur, that might include or exclude certain collaborative and participatory processes of Urban Design (various combinations of cultural, political, economic influence that are specific to each real-world contexts and projects)
- To consider the influences on perceptions and associated actions in strategically focused real-world conditions rather than specifically controlled laboratory conditions.
- To date, limited research has been undertaken to better understand the relationship between spatial computing capability and causes of urban design decision making [see - chapter 3]

Research Approach

Data collection and its analysis is presented on the perceptions and actions of transdisciplinary (including higher education students) and stakeholder participants (including 'The Public'). This is collected within a sequence of urban design events that were planned and/or emerged through the PhD timeframe and are related to the practice of this researcher, as an academic and practitioner of urban design.

The collection and evaluation of data will look to further appreciate how the merging of physical and digital spaces via spatial computing might fundamentally influence participant perceptions and actions within the production and review of early strategic and conceptual design stages associated with urban design. This is considered with some comparison to more established non-spatial computing methods.

Among these broad approaches, this includes the study of under-researched nuances derived and comparatively evaluated from real-world practice-applied contexts.

- Representative collaborators - designers, planners (including students), and stakeholders, including the public.
- Representing real-world conditions, with varying and complex contextual conditions, as is always present when working in urban design practice.

The research is situated within a critical realist view that reality is objectively real but subject to individual cultural and biological perceptive lenses; in other words, it is not observable in its absolute entirety. As such, qualitative data from participants perceptions and actions is sequentially categorised into emerging themes as the research progresses. This thematic categorisation of data, commonly referred in social science research as coding, is used to move from analysis to evaluation. Methods of data analysis are loosely adapted from contemporary grounded theory, specifically applied towards understand social mechanisms, as sought in critical realism. Summarised as a Critical Realist Grounded Theory (method) (CRGT) (Zarif, 2012; Belfrage and Hauf, 2017).

Qualitative Analysis of Data via Thematic Coding

An iterative approach is used to 'code' qualitative raw data in to themes and sub themes, as a method of analysis, to conceptualise and categorise ideas. This provides increasing analysis towards a holistic evaluation. This is not a linear process, but continuously reflexive, developing over the course of the research process, towards the final set of themes that are presented in Chapter 6 Discussion.

This follows a sequence of coding stages, starting with initial flexible codes ('open') drawn directly from primary data, but with reflection on secondary data (literature reviews) and where concepts and ideas are iterated repeatedly and throughout the research process, using 'constant comparison' between data types. As the process continues, the coding increasingly focuses on highlighting key categories and the relationships between them. Iterative phases of deduction and induction provide empirically grounding the results in participant data as a *retroductive* method (Downward and Mearman, 2007; Beighton, 2019). This process is used to define an emergent framework understanding (Timonen, Foley and Conlon, 2018) that is currently not clear.

The approach described, is appropriate as the multi-emergent context of research themes (new technologies and more limited application) presents a situation where the proposing and testing of a of hypothesis was felt to be limiting and potentially lead to deceptive evaluation. Hence, the research embraces reflexivity with the aim of sculping a hypothesis as an emergent output, which might be further tested in the future. Specifically, this research approach seeks to add to our understanding of why collaborative relationships occur as social mechanisms, and to test how this varies when using spatial computing technologies, with relation to differing real-world contextual conditions and factors, for example, by participant background, place, stage and type of design process, or the particular technology used.

The testing of this framework continues through different stages and variable longitudinal real-world scenarios (AlWaer and Cooper, 2020). The intention is to iteratively triangulate combinations of data towards an evaluation that is thus 'grounded' in the data.

Value

This thesis aims to provide an emergent framework for understanding how we <u>can</u> develop spatial computing and to debate where it <u>should</u> provide holistic and ethical benefits to the aims and objectives of urban design. That is, to add to our understanding of a spectrum of capabilities, both practical and perceptive, that might be widely seen as a significant, substantial, and socially acceptable improvement over current methods of urban design development and communication. In addition, this study situates itself within the question of whether the expanding capabilities of spatial computing can fundamentally change the strategic and conceptual nature of urban design processes, as setting up the framework of design aims, and objectives.

This aims to support:

1. Practitioners are looking to improve early-stage design processes and outcomes.
    a. Multi-user testing: explore ways to incorporate the breadth of expert and stakeholder inputs. To improve consideration and therefore suitability of design decisions.
    b. Application: define which SC methods work best for which types of design activity?
2. Members of the public and stakeholders seek ways to influence strategic decision-making.
3. Software developers looking at the potential for new software applications.
4. Researchers looking into future areas of research on these topics.

1.6 Ideation: Reflection on background experience

As discussed further in Section 4.3, the researcher is understood as an active participant. This section provides a foundational context to research themes, direction, and design choices and has been open to self-critique and evaluation during the research. Effectively, this short section is an interview with the self, on those key experiences as an urban designer, landscape architect practitioner and course lead, lecturer/academic which seem most relevant to the research. As such, it is presented in the first person.

Researcher as participant in multiple Roles – 'My Professional background'

My experience of the research themes prior to and during this part-time PhD project have been diverse, multi-faceted, and formed from approximately twenty years of experience prior to this research project. They are summarised to follow, to broadly contextualise my acknowledged influence on data collection.

- Senior lecturer/course lead of Urban Design and Landscape Architecture courses, collaborating in the setup and organisation of many of the case study activities undertaken in this research.
- Urban Designer and Landscape Architect, diverse range of practice experience at different practices, and across different sector focus, including commercial and charity projects relating to participatory and/or collaborative aims.
- PhD researcher: as active participant in using the spatial computing systems in the event contexts, first interviewer, for example, observer/note taker.

My participation in the research often took place within the context of these roles, overlapping and blurring into actions and influences which were hard to separate practically or cognitively. Although not without limitations, these roles afforded a high degree of autonomy over the resourcing and direction of data collection cases. Specifically, this supported the choice of local urban design projects of varying contexts and aims that involved the research themes of multi-discipline and stakeholder collaboration using spatial computing.

Context: Power dynamics in practice

Urban design is in an ideal position to promote aims and objectives that can provide a more collaborative balance between the inputs of multiple disciplines and stakeholder needs. This is because of its early-stage impact, strategic oversight, and guiding conceptual outputs. However, I have found that people's interpretations of what we mean by collaboration vary greatly. In practice, I have experienced many projects, events, and interactions where decisions were made which favoured specific, sometimes narrow agendas, or followed a mindset, or methods that were deeply entrenched in silo thinking (including, on reflection, my own). I have found that the specific organisational, political, and financial forces that surround a project can have a great impact on the resulting design process and level of collaboration.

Example: major parkland project

One significant example in 2008, I played a key role in the proposed redesign of a large urban parkland. This was a complex project, which on reflection would have greatly benefitted from a more collaborative and participatory process. However, the real-world conditions that made up the surrounding context for the project presented significant challenges for the collaboration and involvement of key stakeholders:

Small team, limited capacity

Though a large project, it involved a very limited number of designers, initially led by two landscape architecture staff: one as senior project lead with limited time (expensive rate, much project leading experience), and me, still a relatively early career undertaking most of the longer time design production (cheaper rate, visualisation/design capable). In terms of staff resources, there was no time allocated for anything beyond* established 'best-practice; design tasks (*such as reflecting on the wider process, quality of collaboration, etc.).

Limited input from other disciplines

The first outline masterplan phase, spanning three months, involved site visits and light interactions with the local council (client) via one planner. Later, 'Specialist' advisors were brought into the project to undertake specific areas of design, or to bring expertise to gaps in completing regulatory requirements. Specifically, consultant architects worked on a new statement building, a transport planner would look at improving movement and access to the park, water specialists would advise on potential flooding mitigation, and an artist would develop public art pieces to represent the local community and culture. Although there was occasional discussion, setting brief and broad aims, the process for each was separated, with ideas worked up remotely and for emailed input into the wider plan. To varying degrees, there was conceptual, stylistic, and practical alignment and misalignment to our wider proposal.

Late community involvement

Many months later, it became clear that there were community discussions regarding the proposal to redesign the park. It was decided that a 'consultation' event would be needed. This had several issues; despite well-meaning aims and efforts, it was on reflection a highly tokenistic activity:

- Too late in design process - initialised late and then took additional time to organise, public input far too late to impact on design decisions

- Inappropriate social and practical context - hosted within a very loud festival, near the main stage, misaligned activity. Presented a highly disruptive barrier. Could not fully hear each other for most of the time
- The absence of design input (Co. Design) - two 'design concept options' were shown, one had been developed over many months, another had been made quickly as an option for the event – but was far less considered nor desirable to the designers, or council team. The public was presented with no real choice.
- Inaccessible communication format: The use of a printed plan, with overwhelming additional information on the sheet, presented significant barriers to understanding.
- Limited participant data collection: Local responses were collated only from a closed question post-event survey.
- Limited demographic – specific age and ethnic background, far from representative of the local culturally diverse community.
- Disruptive, biased influence - a niche lobby group/commercial entity attended with a large banner, attempted to influence design decisions in their favour.
- Low engagement: Very few came into the event space from the wider festival. This event was not repeated.

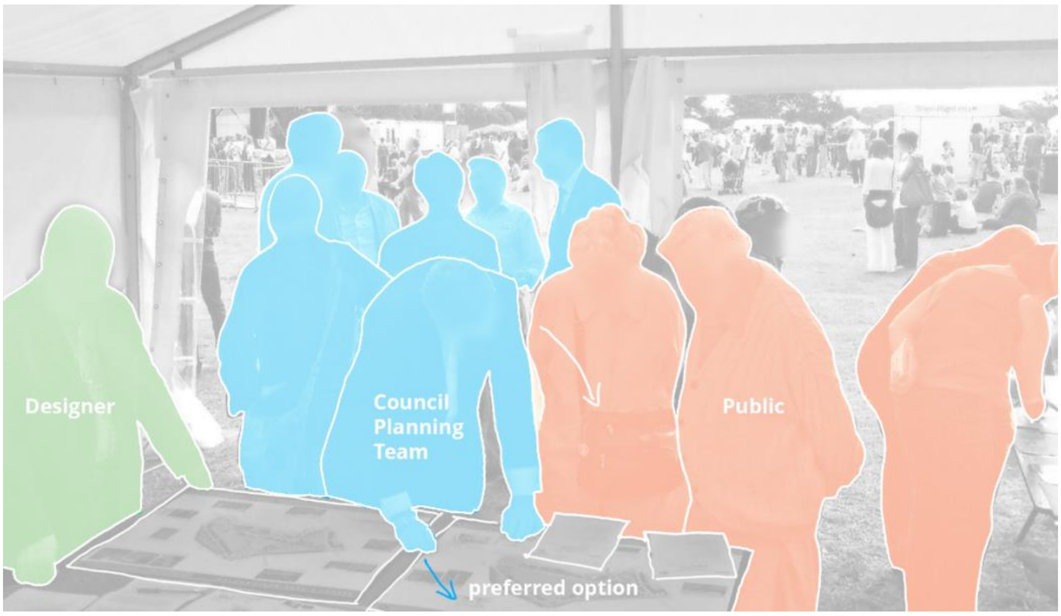


FIGURE 1 – 'CONSULTATION' EVENT - INSIDE TENT AT LOCAL FESTIVAL

The number of points for improvement as outlined above, I do not feel were due to malice but are symptomatic of common factors influencing real-world practice: limitations of time, knowledge, and transdisciplinary experience across complex scenarios and involving a diverse body of stakeholders, as well as needing to manage competing aims and objectives.

Participatory Approaches

Later in my career, reflecting on prior experiences, such as those detailed previously, I sought out experience (as a volunteer) at an urban design charity that specifically focused on community co-design. The methods for community engagement were considered much more aligned with participatory principles:

- Use of accessible, mixed media to represent design ideas in different ways for diverse audiences and enabling ways for the public to use and communicate ideas visually.
- A workshop approach, guiding users towards understanding the process and techniques used.
- Situational, on-location in the local community centre. Not only was this beneficial to more genuinely involve people in decisions that directly affect them, but I was able to see that my designer's expertise and skill set was not put aside but enabled me to become a key facilitator to promote deeper considerations of physical and social context for members of the public to situate their ideas, giving feasibility to expectations.

Consultation > Engagement > Participation

Relating to Arnstein's (1969) ladder of citizen participation, I have found the phrase 'consultation', and to a lesser degree 'engagement' to be most used by designers, clients and councillors, who rarely talk of 'participation'. In many cases, this is likely an unconscious echoing of established 'industry terminology, related to the time constraints of professional design, rather than an intended, deliberate statement, but its use aligns with the dominant approach/underlying power structure at play. The power for making decisions lies greatly with planning and design teams and, if not more so, with developers and politicians. More commonly than not, these decisions are not open to the influence of wider stakeholders or the public. The key exception and more common use of the word 'participation' is where specific groups are involved in community activity as practice specialism.

Reflection on Academic Practice

I have been involved in various academic activities relating to Urban Design and significantly, leading the development of MA in Urban Design at Birmingham City University (BCU between 2018-current), which gave the opportunity for varied debate with academic and invited practice colleagues across design and planning disciplines. This experience, at least in my local academic context, has evidenced the sentiment presented by Cuthbert (2010) that there is no clear consensus or agreed direction for Urban Design, practically, conceptually, or philosophically. Discussing with various colleagues, varying understandings, expectations, and processes have been presented, though with a common appreciation of its dynamic complexity and acknowledging the need for multiple, collaborative perspectives. I felt that interest in Urban Design aligned to genuine interest and desire for collaborative practice as an understanding that this involves compromise, flexibility, and critical reflection on discipline mindsets.

Exploring Co-Urban Design

My academic experience in setting up and running yearly exploratory collaborative modules has indicated two repeating major challenges of the co-design process. The first is that the navigation of interpersonal and group relationships and roles is challenging and time-consuming. The second is that new approaches from the perspective of the individual, no matter what they are, tend to initially be treated as outside approaches that are not quickly integrated into the design process. Both factors added greatly to the time taken to undertake the collaborative process.

- CoLAB: Strichley High Street redesign, 2014 – *Students did not find participatory engagement with the public challenging. They have some innovative ideas, but generally had not thought through the process and made many basic mistakes when speaking to the public, which they learnt from as a process.*
- Minerva Works industrial re-use, 2016, and High Speed 2, Curzon node wayfinding, 2017 – various mixed discipline groups varied in their collaborative success related to the makeup of the group, significant disruption was caused by lack of effort from some members.
- Chelmsley Wood community design actions, 2020 – barriers presented by power and class affect ability to appreciate others' experiences and desires. It was a challenge for mostly well-off student designers to deeply understand the constraints and living conditions.

Co-Urban Design with spatial computing

Colab, Playground of Hybrid Realities (2018) explored conceptual ideas for Augmented Reality (AR) that could enhance a primary school playground for educational play and sport. Both students and stakeholders (schoolteachers) had very little prior awareness of AR or its potential capabilities. They were surprised about how much was already available and how much could be done. The students showed a general understanding of AR capability, though all groups stuck to applying tried and tested ideas, with outputs being an adaptation of examples shown to them, then applied to the specific context.

School children's playful ideas gathered through hand-drawing activities provided a highly fertile ground for exploring the potential of AR applications via a possible overlay of storytelling elements into the real world. Several teachers remarked that this has huge potential for future engagement and learning. One of the dominant ways to create AR content at the time was to use the Unity game engine. Architecture and design students found the learning process slow and tedious, having only a limited time to learn complex and fundamentally different interface compared to architecture software. There were many technical issues blocking quick understanding and progress towards any kind of useful output. Students were reluctant to put effort outside of their established learning. The final outputs indicated that no students continued to practically use Unity (or AR) beyond the introduction sessions, but were able to explore and present conceptual ideas for a future AR school playground.

Adventures in Hybrid Realities 2019

Looked at high-speed rail development (*HS2 in Birmingham*, 2024) through an imagined future of personal user journeys, experienced with augmented narrative overlay. Novel future concepts and ways to communicate were presented easily using established means (photomontage and physical models) and challenged student preconceptions. Whilst able to develop AR concepts freely, the technical implementation proved much more difficult and limited: Testing 'marker-based AR', using established game engine (*Unity*, 2024; *Vuforia*, 2024), was single low resolution model and projection mapping software, higher resolution but static, complex setup (*HeavyM*, 2024). Though 'tech demos' were shown as basically possible, there was a large gap between exciting concepts and very limited actual demonstration, especially with mobile AR.

Students and I were also able to have first-hand experience with a range of AR hardware devices from Microsoft Hololens (1) and Google Glass, which all had strengths relative to each other, such as less weight, greater resolution/graphic capability, fundamental weaknesses, small field or view, poor battery, and unreliable.

FIGURE 2 - AR TECH DEMO, GOOGLE GLASS AND MICROSOFT HOLOLENS

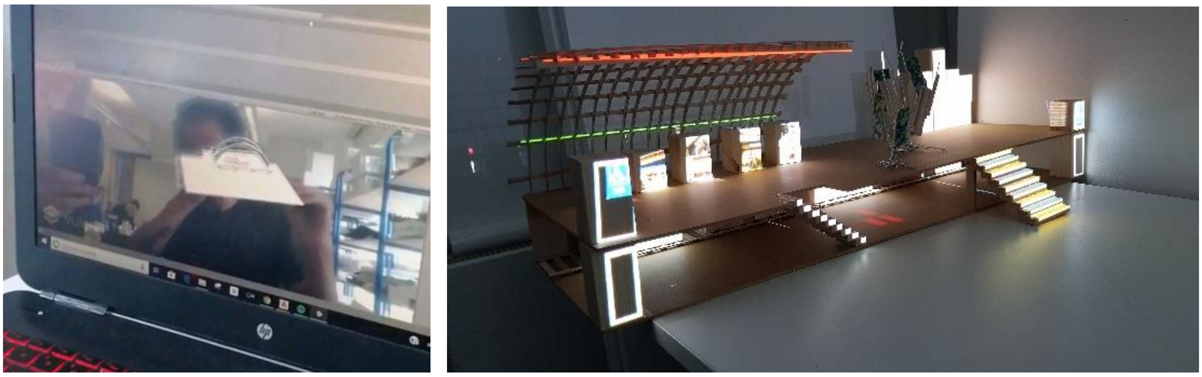


FIGURE 3 - EXPLORATIONS UNITY AND PROJECTION ON PHYSICAL MODEL

JEWELLERY MULTIPLICITY 2021

AR for design communication was explored for communicating Jewellery narratives in a virtual exhibition room (during Covid19 lockdowns). The students were able to use off-the-shelf AR software on their personal devices as it became increasingly available and accessible. As with previous year's outputs, there was a gap between deep exploration of highly immersive, spatial concepts (*Final Experience*, 2021)), and the actual AR outputs, which were very limited display of one, non-animated 3D model. This was due to a combination of the limited capability of the software, limited skill set/experience of the groups (including more broadly, of 3D modelling), and the use of variable type/spec personal mobile devices. The context (covid19), especially the remote interaction during the collaborative process, changed the nature of the process greatly, strengthening work focus, but weakening social bonding. There was less ability to support students with technical issues, as the details of their hardware and process could not be seen/shared easily, making the process quite uncertain for all involved.

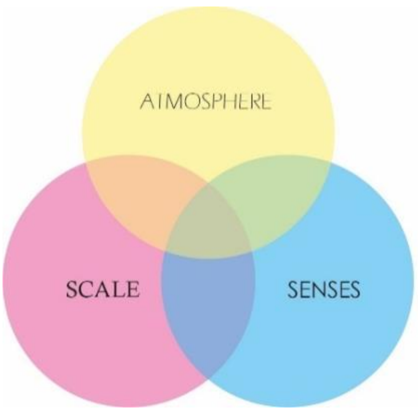


FIGURE 4 - CONCEPTUAL THEMES EXPLORED FOR IMMERSIVE, DESIGN STORY TELLING

CoLAB modules 2022, 2023

These modules formed part of the data collection for this PhD research project and were designed with relation to the research aim (see sections:

5.4 - Co-Reality Brum 2022

5.6 - Reimagining Southside 2023

2 CONTEXTUAL LITERATURE REVIEW

This chapter provides a deeper review of key topics as a broad introductory literature review. A critical review of contemporary research papers, including a deeper exploration of the research gap (gaps), is presented in the following Chapter 3 - State of the Art Literature Review.

This chapter defines urban design as an activity with approaches and processes towards a collaborative, 'co-urban design', and spatial computing as an area of technology with emergent potential. This also sets out the main problem/opportunity for abstract versus immersive communication as the foundational rationale for this research.

In simple terms, the overall themes of this project and their relationships are as follows: Urban Design - Co-Design: spatial computing; impact on Reality. As the research question: *How might Collaborative Urban Design (Co-UD) influence and be influenced by the incorporation of spatial computing (SC) methods in real-world practice?*

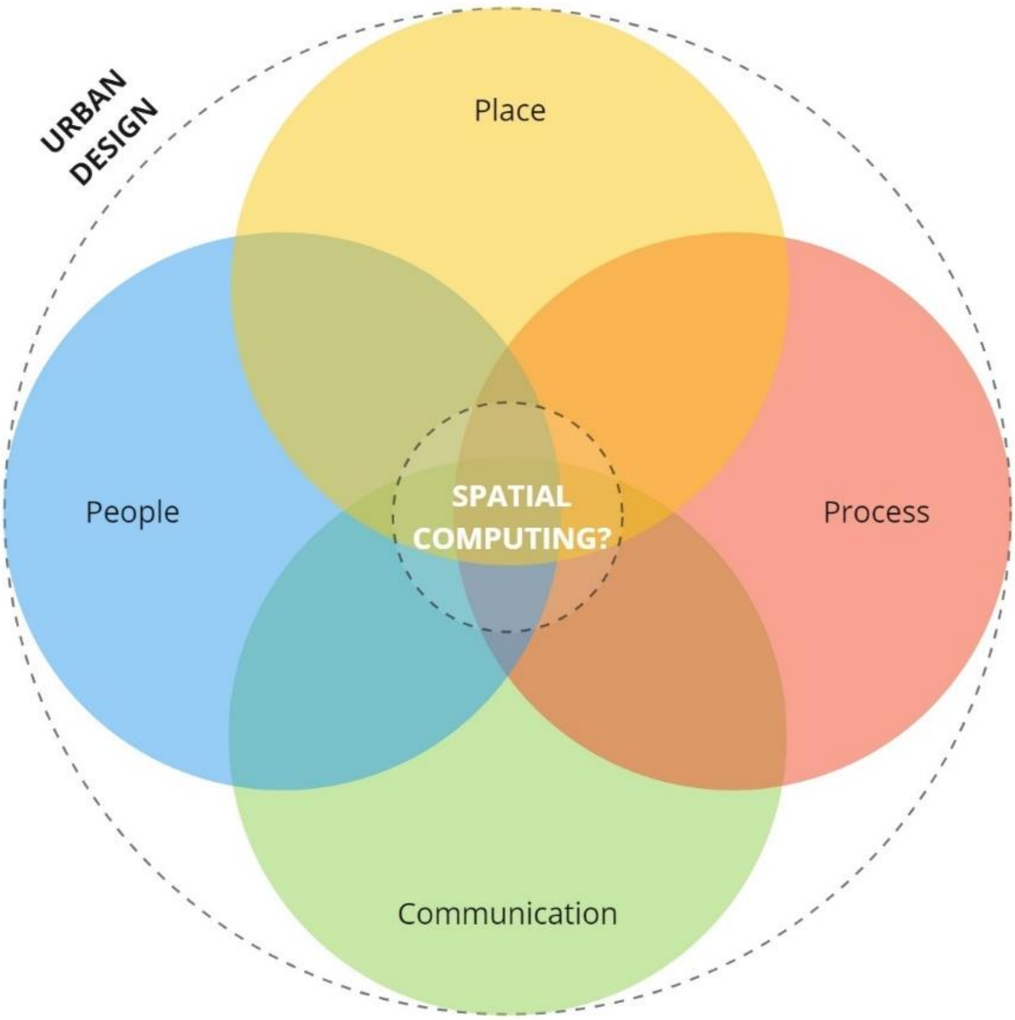


FIGURE 5 - RELATIONSHIP BETWEEN TOPICS

2.1 Urban Design Place and Process

This first section provides an introductory overview of Urban Design, highlighting the key debates around its contemporary practice as well as why collaborative work is a particularly important aim for urban designers.

Urban Design: contesting a transdisciplinary, strategic field - Gehl (2011) summarises Urban Design as a 'design activity for the *improvement* of function and experience of urban places'. While this provides a succinct definition, the following section explores these defining points to understand the research problem more deeply. First, a short overview of the key principles must be defined.

What does Urban Design look like? - focuses on the early stage, conceptual/strategic of built-environment process. Design outputs often provide indicative proposals, as a vision that guide the overall aims and objectives of more detailed stages that follow (Black and Sonbli, 2019; Urban Design Group, 2019).. Aligned to this, urban design often uses framework communicative methods such as diagrams, indicative illustrations, which aim to instil fundamental principles for the future delivery of specific detailed design elements, e.g. buildings, streets, and parks, by specific design disciplines, e.g. Architecture (Meeda, Parkyn and Walton, 2007; Štefancová *et al.*, 2020).

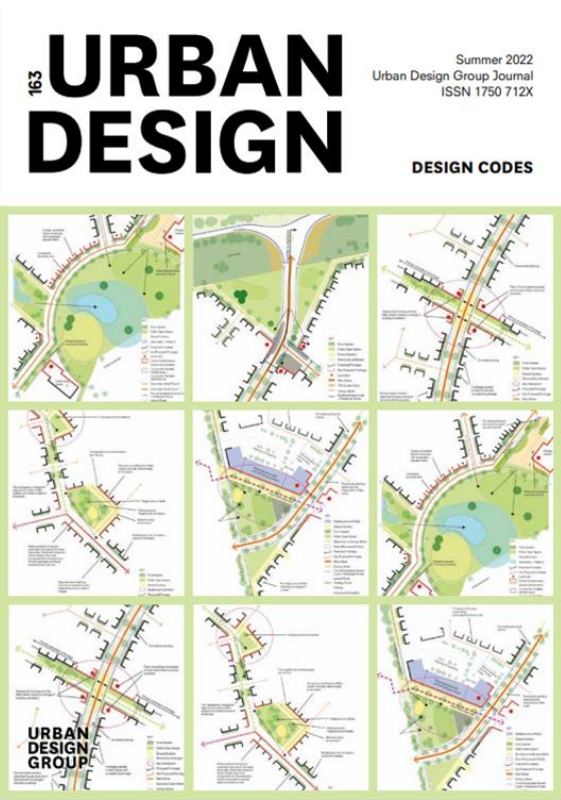


FIGURE 6 - URBAN DESIGN MAGAZINE: DESIGN CODES

(URBAN DESIGN GROUP, 2023)

Who undertakes Urban Design?

Although everyone living or interacting with urban areas has an influence, more explicit actions are undertaken by a range of built-environment professionals, and 'urban designers' are often qualified or working planners, architects, landscape architects, etc. The process also involves developers and key stakeholders, such as clients, funding bodies, governmental bodies, as well as community groups and the public as end users of the place.

What makes for an improvement?

It is not easy to qualify or quantify an improvement in an urban condition if we are to consider the opinions of everyone involved or impacted. The challenge for urban designers is to balance an extensive range of perspectives and interests at play in urban contexts.

> *Urban design is "the collaborative and multi-disciplinary process of shaping the physical setting for life", by "establishing frameworks and procedures that will deliver successful development by different people over time." (Urban Design Group, 2019).*

The Urban:, 'Place' as a context for Design

Combining the common words 'urban' and 'design' might suggest an activity that is easily understood. However, the urban context is an extensively multilayered, complex entity born of the incredible diversity and changeable spectrum of human culture. It can be understood scientifically as a distinct human ecology created by us and hosting our range of social and practical functions for what we define as" civilised' life. Within this context, it is subject to varying political, socioeconomic, and environmental debates (Jayne and Ward, 1996; Cuthbert, 2007). This is understood by gaining appreciation of the social context in relation to the collective evaluation of design outputs (Black, 2018) (*semiotic appreciation*), as well as the expectations and aims that relate (Jayne and Ward, 1996).

On this, two key perspectives present themselves clearly in the often-cited 'seminal' works of Urban Design (of the late modernist period, 1950-70's). These can be summarised into the broad and related concepts of, the:

- Tangible – an appreciation of the urban as a physical object to be perceived from a visual, spatial perspective: as individual; and social perception of function and character, for example, (Lynch, 1960; Cullen, 1961)
- Intangible – an appreciation of the urban as a social, cognitive entity, to be understood as a changeable societal structure: influenced greatly by political, socio-economic forces, for example (Jacobs, 1961, 1969)

Most contemporary best practice considers both of these lenses to be part of an inseparable relationship; as 'separate sides of the same coin' (Araabi, Carmona and Foroughmand Araabi, 2017, pp. 108–110). However, in reviewing a range of contemporary research (1999-2016), in an attempt to confirm such a contemporary consensus, Cozzolino *et al.* (2020) found that more research had been undertaken on tangible concerns than intangible concerns.

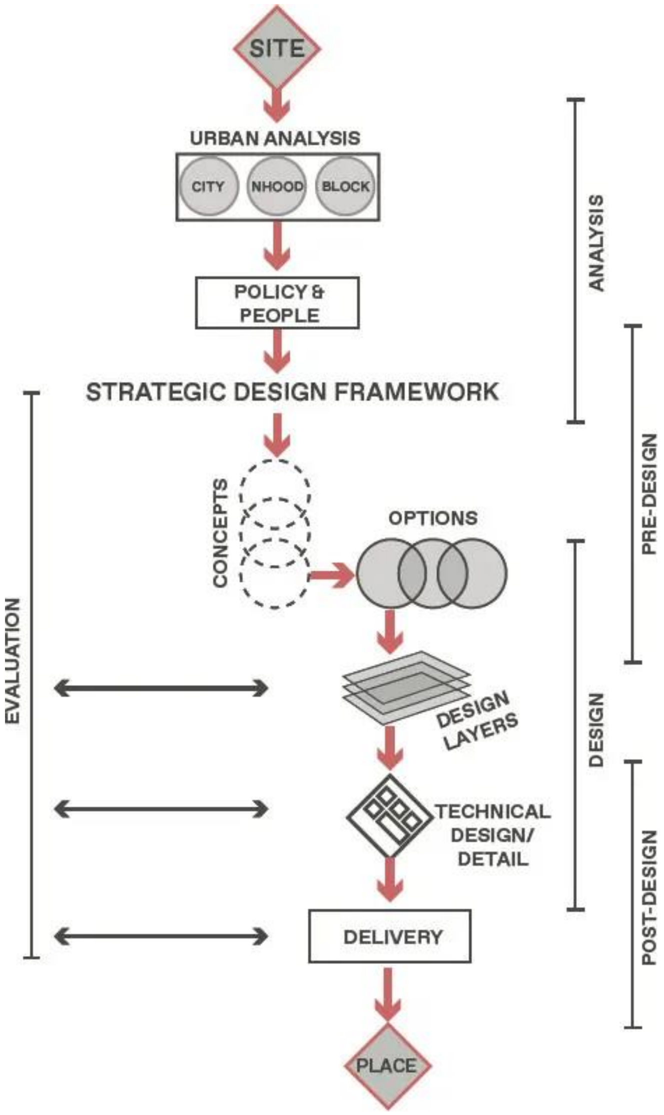


FIGURE 7 - URBAN DESIGN PROCESS

(Black and Sonbli, 2019)

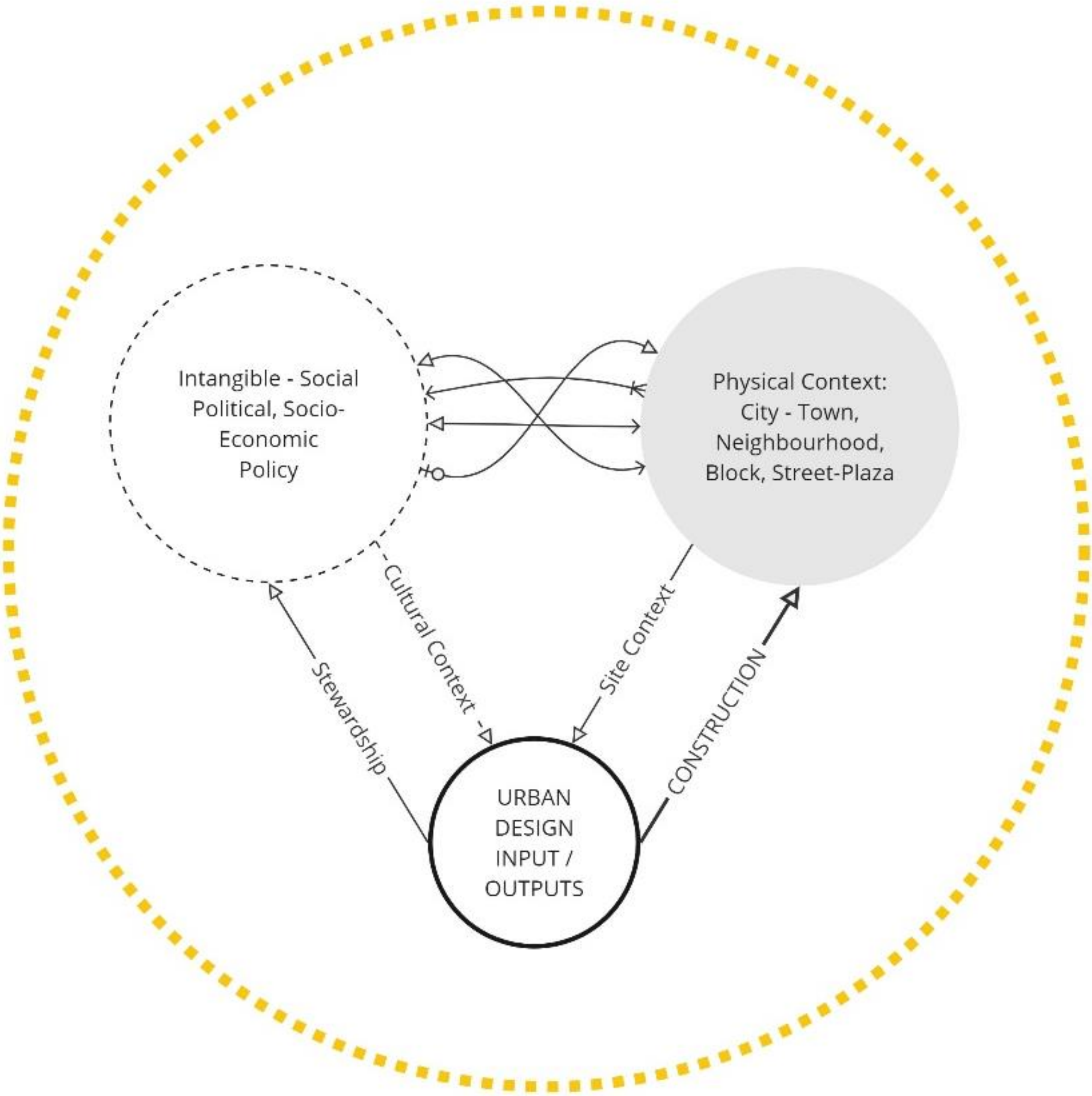


FIGURE 8 - CONCEPTUAL DIAGRAM: RELATIONSHIP OF 'PLACE' (AUTHOR)

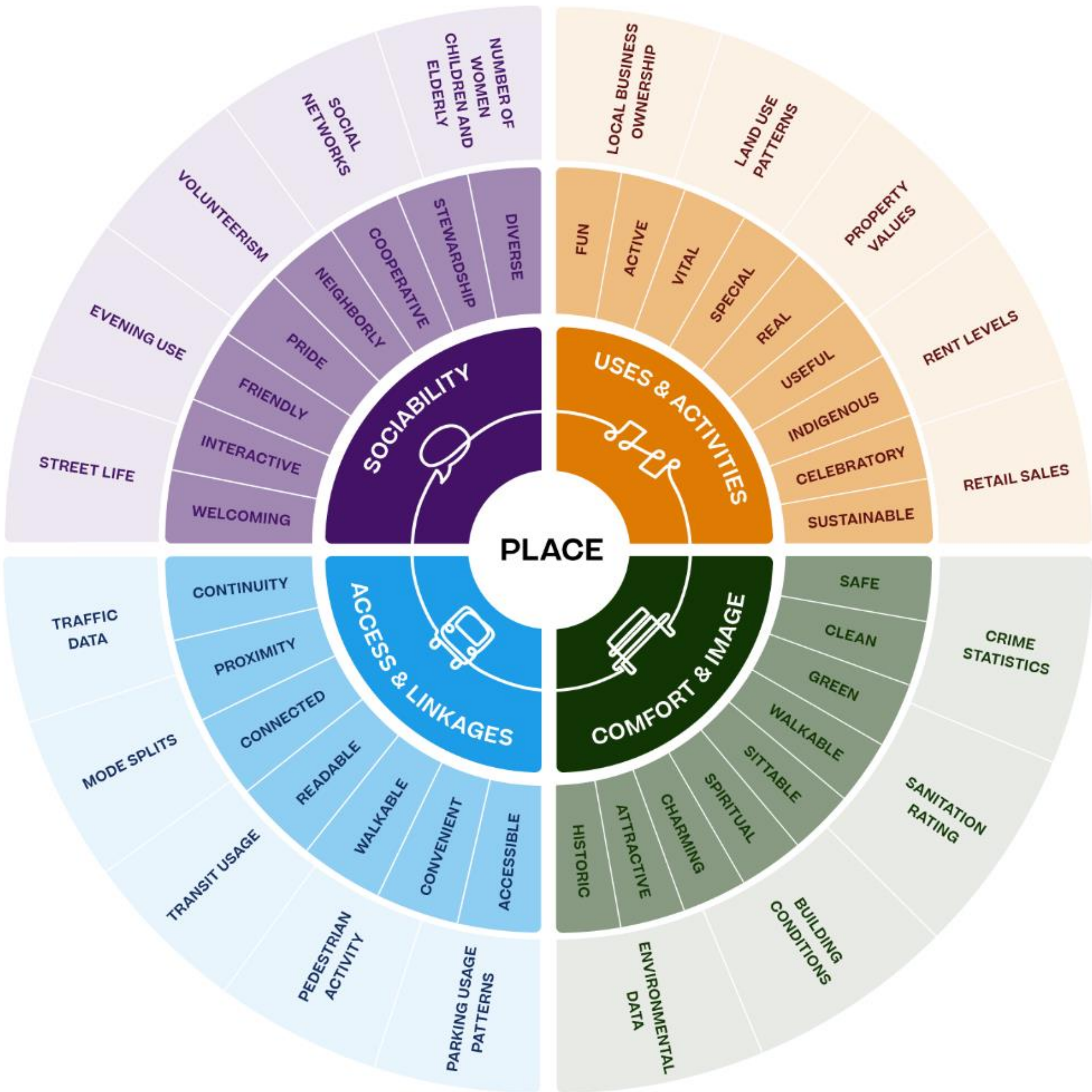


FIGURE 9 - EXAMPLE MODEL: KEY LAYERS AND SUB-THEMES OF - WHAT MAKES A GREAT PLACE?

(*PROJECT FOR PUBLIC SPACES*, 2024)

A Contested Field of Study

> *"how urban design should be done remains an issue open to different subjective interpretations based on different ideas of the collective and public good" (Cozzolino et al., 2020).*

In attempts to understand the complex relationship between physical and social constructs, recent debates have questioned the nature and credibility of urban design knowledge itself (its epistemological foundations). There are questions of whether much of the foundation for design decisions is derived too heavily from often-repeated professional hearsay, relying on rhetorical, assumed truths (Cuthbert, 2010), weakly tested hypotheses, and with unsubstantiated claims towards proper testing (Marshall, 2012). However, others have argued that urban design cannot be understood as an empirical measurement alone. Rather, a mix of social and subjective complexity is *"a particular form of diagrammatic socio-spatial knowledge that cannot be reduced to either words or numbers* (Dovey and Pafka, 2015).

Moving beyond debates of objective 'science' vs subjective views, (Dovey and Pafka, 2015) promote a need to include philosophy in urban design theory, by drawing on conceptions of a reality as being in constant flux, they cite (Deleuze and Guattari, 1987)*; and as furthered by DeLanda* (Ball, 2018), where the urban might be understood as not definite, but rather an unfixed assemblage of components, as highly changeable, temporal (Muminovic, 2015), and that connect through the *"productive flows, synergies and alliances between things rather than things in themselves* (Dovey and Pafka, 2014). It is alive.

The only certainty presented is that there is fundamental disagreement between theorists: *"Urban Design remains a discipline without a clear mandate or process"* (Black and Sonbli, 2019).

Urban Design Aims, Objectives, Process and Outputs

If there are no absolute, uncontested theoretical principles of Urban Design, there are at least some repeating principles. These are commonly discussed in practice and have developed over time. The focus of urban design theory and activity is largely on the overall defining structure and relationship of an urban place (holistic thinking), rather than the specific details of each sub-discipline. Related to these strategic aims, the products of urban design are presented as framework approaches (English Partnerships, 2000; Carmona, Heath, Tiesdell, 2003, pp. 5–6), or now often referred to as 'design codes', particularly in UK policy (National Model Design Code, 2021).

For example, Urban Design is concerned with the broad form, massing, utility, and access more than the specific construction or specifications, as would be dealt with to follow as architecture or landscape architecture. It is interested in the whole product, not a sole building, road, or park, but how these transects impact the overall urban system and form a unique place (Carmona, Heath, Tiesdell, 2003; Lang, 2005).

Urban Design Process

The process of urban design: The stages, arrangements, and modes undertaken have a direct influence on the product: the drawn and otherwise communicated design outputs, which hopefully result in a physically constructed urban *place*. The term 'Place' is regularly referred to, with implied integrative specific context meaning, as both a specific physical environment and aligned social reality (Faehnle and Tyrväinen, 2013). However, this is not static entity, but ever changing, alive (*A Materialist History of Cities*, 2011; Dovey and Pafka, 2014).

Urban design can be understood as intertwined or immediately following stages of the process of planning (urban planning). As such it is 'early stage' relative to multiple stages of wider built environment design and construction process (as 1 - below). Though it also often considers the whole process in a strategic sense, especially with relation to holistic issues, such as long-term design phasing, as well as post-occupancy management and stewardship (3):

TABLE 1 - URBAN DESIGN INFLUENCE ON STAGES OF BUILT-ENVIRONMENT PROCESS

1	Context analysis, design brief and concept, strategic design/masterplan – creating design framework (or/'codes')	Urban Design – key focus
2	Detailed design and construction - Increasingly 'zoomed-in' – undertaken by architects, landscape architects, etc.	Influences via framework
3	Post-occupancy stewardship and critical reflection on best practice	Urban Design – element of

Summarised from (Carmona, 2014; Black and Sonbli, 2019)

In real-world projects and development, the specifics of the urban design process can vary. For example, in terms of the stages used, the level of appreciation of context, the amount of testing through iteration, and many more aspects. Influence comes from specific policies via the surrounding political-economic context (Carmona, 2014), as well as local contextual conditions.

These factors will also be determined differently by different teams, types of work, differing aims, etc.. Carmona (2014) defined the causes of this variability as an interplay between various disciplines and stakeholder arguments for design vision: negotiated power dynamics of development, absolute practicalities of space, and future management and security issues. However, when combined with variable physical conditions, this can create conditions for far more dynamic and less linear processes than may be summarised/theorised. This is particularly the case when established conditions are sensitive and require significant retention of the existing design attributes (Lim, 2017).

Owing to this difficulty, there are various established methods of evaluating place-based problems/ opportunities in the analysis stages of a design process–for example:

- *SWOT: Strengths, Weaknesses, Opportunities, Threats*
- *PEST: Political, Economic, Social, Technological, Environmental, Legal and Ethical* (Vardopoulos *et al.*, 2021)

Such complex analytical processes can be supported by systems that manage and guide the quality of outputs. Their design should supports variable processes and iterative 'design feedback loops', as "good' design process' (Gil, Duarte and Syntax, 2008).

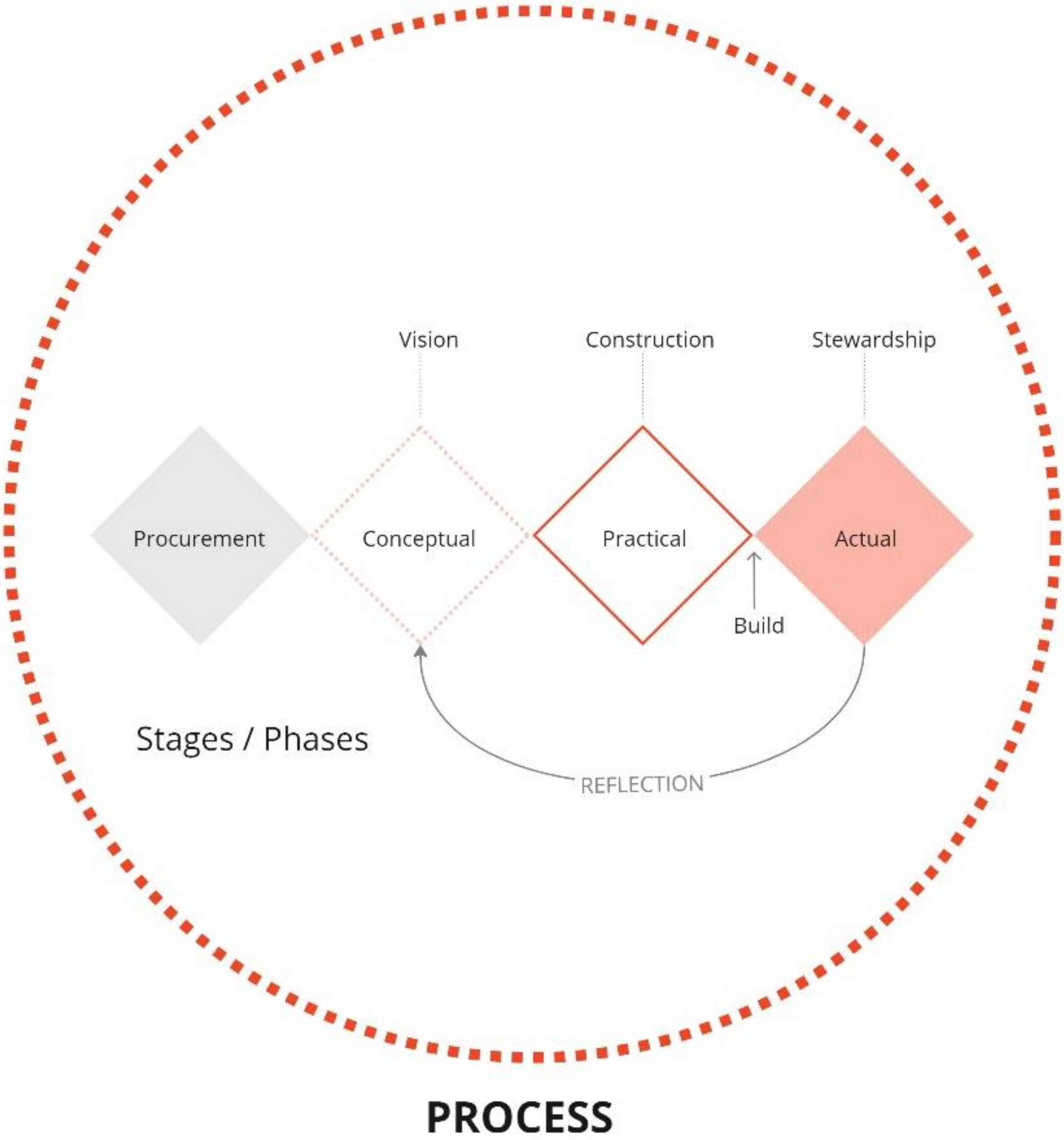


FIGURE 4 - CONCEPTUAL DIAGRAM: RELATIONSHIP OF PROCESS (DESIGN, DEVELOPMENT) (AUTHOR)

A Strategic, Generalist practice

Professionally, urban design is primarily entered into as specialism following prior training in areas commonly considered as specific discipline areas, notably those of planning, architecture, and landscape architecture. This is evidenced by the majority of UD courses in the UK being postgraduate, or pathway from other disciplines (Urban Design Group, 2024). However, for those professionals, as a career specialism, it is not of focusing on more detail but of broadening appreciation of other fields, towards more strategic aims, and larger scales of design. As a topic, it might therefore be better described as a generalism or a holistic strategy that aims to focus on the relationships between various actors in the flexible processes involved in the creation of urban places (Rizzo and Galanakis, 2015).

> *"Understanding and creating integrative spatial quality needs a relational and transdisciplinary understanding" (Khan* et al.*, 2014)*

While people from particular professional backgrounds bring value through their own expert knowledge, they also often lack knowledge of other disciplines and how their expertise might relate to that of others (Alrashed *et al.*, 2015). Urban Design can be seen as an attempt to close these divides. Therefore, for the evaluation and design of urban areas to be widely considered useful, there must be some acknowledgement and consideration of the multilayered interrelationships between highly variable processes that influence the perceptions of practitioners and wider society.

In attempts to guide practical outputs that inform decision-making, various studies have attempted to clearly define the spectrum of urban design. Arranging urban design into practical categories, Carmona (2003) defined eight 'dimensions': temporal, perceptual, morphological, visual, social, functional, design governance, and place production*;* the latter dimension was subsequently expanded to include the (political) power relationships which influence urban design production (Carmona, 2014).

Urban Design Evaluation

> *"There is no neutral, objective design. Design is subjective. Of course. Why shouldn't it be?" (Rittel, 1987)*

As discussed, the range of influences on urban design is tremendously wide and variable (Carmona, Heath, Tiesdell, 2003). With that comes a whole range of perceptions, agendas from professional and wider life experiences that inform different frameworks and categories for judging design qualities (Cabe, 2001, p. 26; Antoniou *et al.*, 2019). In design process and outcomes, subjective judgements and preferences (and biases) are made no matter the extent of training to be 'objective'. Rather as design arises via a series of choices, through combinations of arguments towards certain outcomes (Rittel, 1987). No more so is this the case than the idea of what is beauty, which is commonly noted as *'in the eye of the beholder'*. Through training, design professionals may be better at using words and producing visual communication that gives credence and weight to decisions. In discussing design, many will lay claims to universal truths in this regard, but when asked to provide an extended rationale beyond rhetorical reasons, their argument becomes difficult to substantiate (Black, 2018).

> *"all people, when becoming aware of their surroundings, each have a different, embodied and pathemic, sensory perception and cultural experience"*
>
> (Bellentani, Panico and Yoka, 2024)

While the average person on the street may not be able to explain their thoughts on a place with details of their theoretical basis, their reasons will align with the meaning they assign to the physical form and materiality of places and activities, understood as semiotics (Lagopoulos, 2019; Bellentani, Panico and Yoka, 2024b). Sociopolitical arguments are embodied in the perception of design (a place). An individual's cultural, ideological (epistemological) position aligns with their perception of a design's success, quality, beauty, and so on.

> *"A street pattern may be a grid, the city center may have tall buildings…various kinds of connotations may be attached to them ("monotonous arrangement," "oppressive"*
>
> *(Lagopoulos, 2019)*

At the same time, too, views are not entirely static, but "of interpretation and reinterpretation' (Hiller and Goodbrand, 2016). Persuasion in these circumstances is the major pursuit of political domains and has the most significant influence on the planning process. This is clearly evident in the debate on whether and to what extent, to involve the public in decision making – as 'levels of participation' (Arnstein, 1969). This is often perceived as trickier due to political agendas and bias which adds to complexity.

2.2 'Co-Urban Design'

In the context of a tremendous potential variety of influences, Urban Design is a process often stated as needing 'co-design' approaches, that is, which encapsulate collaborative intent to attain multiple views to be understand the complex urban conditions. In practice, this means transdisciplinary: as between and beyond various disciplines; and/or participatory: involving stakeholders, particularly the public. Dupont *et al.*, (2012) highlight this attempt, as to ensure a collective integration of knowledge, from many views and subject areas. Considering this diversity, it has been asked whether urban design is a distinct discipline, a field of study, an aim, or simply a collaborative design context in which various people come together to achieve an 'urban' product (Cuthbert, 2010; Black and Sonbli, 2019). It typically brings some Key collaborators:

1. Discipline Practitioners (those 'in Practice') – architects, designers, engineers and planners working in areas of the built and natural environment, which might include those researching, and studying within these areas: i.e. academics and students
2. Stakeholders - the public (end users), clients/investors (developers), governments and organisations

(Black and Sonbli, 2019, p. 74)

In a general sense, the aims of collaboration are defined as actions and processes towards increasing innovation and creativity (Robinson, 2000; Parjanen, 2012), and for gaining 'collaborative advantage' in challenging contexts (Huxham and Vangen, 2000). For example, in urban design, the addition of multiple voices can act as representative diversity, which facilitates design decisions through multiple viewpoints and areas of experience in support of project acceptance, and hence, social sustainability (Lang, 2005; Luyet *et al.*, 2012; Thomas, 2016). Strong approaches to non-tokenistic collaboration at the team level relies on additional effort and planning at the outset.

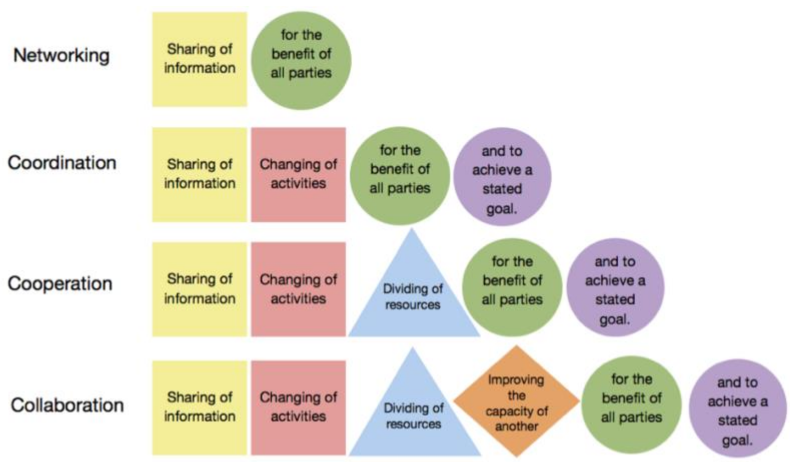


FIGURE 10 – THE SEARCH FOR COLLABORATIVE ADVANTAGE (HUXHAM, 1996)

Co-Design as Participatory

The related idea of participation is an aim towards genuinely opening powers of decision-making, to attain representative levels of involvement from a diverse representation of stakeholders. An implication within this aim, is to open access for who will be directly impacted by any changes and who might typically have the least power (Arnstein, 1969); those who are deprived or disenfranchised. This is most commonly discussed in the classical democratic ideal of 'the public', evoking debate on morals and the politics of representation (Björgvinsson, Ehn and Hillgren, 2010). However, this is also a consideration for collaborative practice in the sense of aiming for parity between the influence of all the various disciplines and the professional stakeholders who may input. This points to an aim towards some kind of collective truth, rather than decisions made only in the name of certain established power structures. It raises several questions, of whether this is idealistic or realistic. Or at least, to what extent; and if possible, what are the real-world tangible benefits?

Participatory inclusivity from the general public has been a long-standing argument presented in academic and practice literature for urban design (Jayne and Ward, 1996; Carmona, Heath, Tiesdell, 2003; Lang, 2005). At the same time, it is acknowledged to be difficult to achieve in practice due to the typical complexity of perceptions and the temporal, chaotic conditions (Gaudio, Franzato and De Oliveira, 2017). The need to consider such a complex spectrum of knowledge bases, expectations and political-social hierarchies (Arnstein, 1969), as discussed (chapter 2.3) is a tricky problem as claims to design 'quality' and 'success' are particularly contestable (Dovey and Pafka, 2015; Black, 2018).

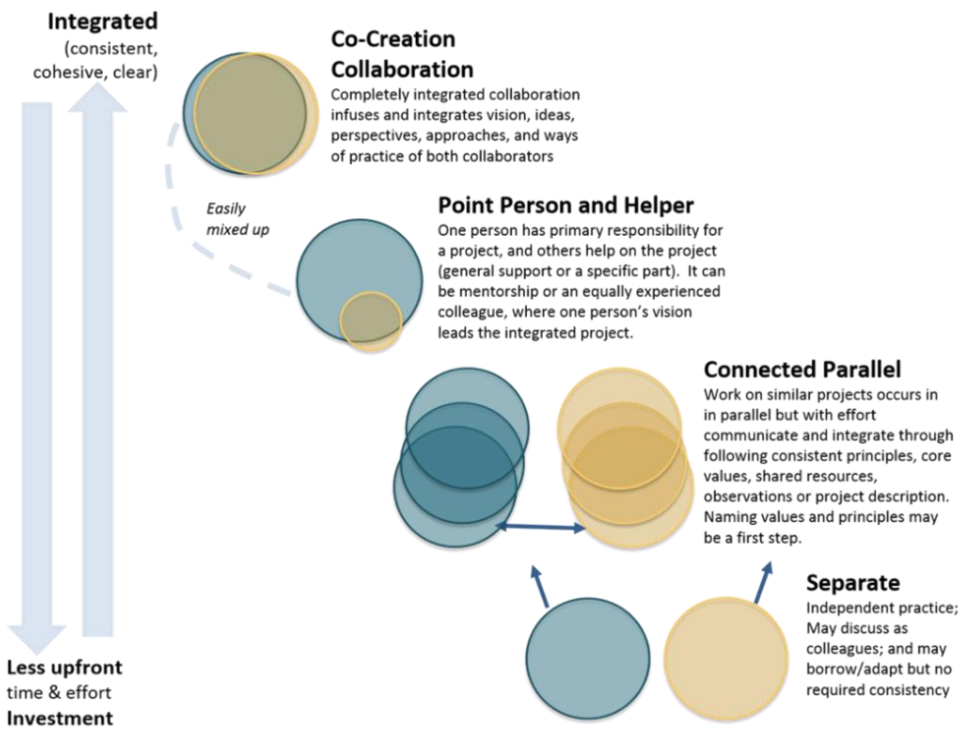


FIGURE 11 - FOUR MODELS OF COLLABORATION (KUSTRA AND HOESSLER, 2019)

Equal participation by a range of stakeholders is a key component for inputting a wide range of useful local knowledge to better inform design interventions (Ataman and Tuncer, 2022). This is not only a practical concern, but political too, as often discussed equity relates to involvement and input from the 'have nots', as well as justly reviewing the level on a scale of meaningful input - from no equity, to total equity (Arnstein, 1969). This raises philosophical questions for collaborators about their own position of power, their particular biases, and agendas. It has also been argued that, while deserving equal opportunity, the reality is that we are not all the same experience or skill set. While acknowledging and attempting to mitigate inherent bias towards designer's input (or other experts), a respectful negotiation around differences can build collective strength and allow differences in approach and level of input to work towards shared goals (Bowen et al., 2016). Recognising individuals' particular strengths should be utilised but not allowed to dominate. An open access approach for 'democratic innovation encourages the discussion of difficult debates with potentially opposing views, so that all are actively involved in co-creation (Björgvinsson, Ehn and Hillgren, 2010).

Choosing a particular method is not so straightforward, as ideas of participation have become so extensively covered in UD/planning research that today we must navigate a wealth of potential methods (Münster et al., 2017). Aligned to this, and as discussed earlier in this chapter, the lack of broad consensus on the nature of urban design reduces the clarity of intent for stakeholders who are not familiar with the subject, or debate (Cozzolino et al., 2020). And if looking retrospectively at past decisions, it can take a long time to see a fuller picture of how certain decisions/actions were made, due to a lack of full records or access to those records (Larkham and Conzen, 2021).

In terms of processes, Tomkins and Lange (2019, p. 10) suggest that participatory workshops often follow a specific staged workflow, which over a number of sessions combines to facilitate a holistic approach: starting with communication of project overview, flowing into spatial analysis, and then design collaboration. This process can require considerable additional effort and extended timeframes for success (AlWaer and Cooper, 2020).

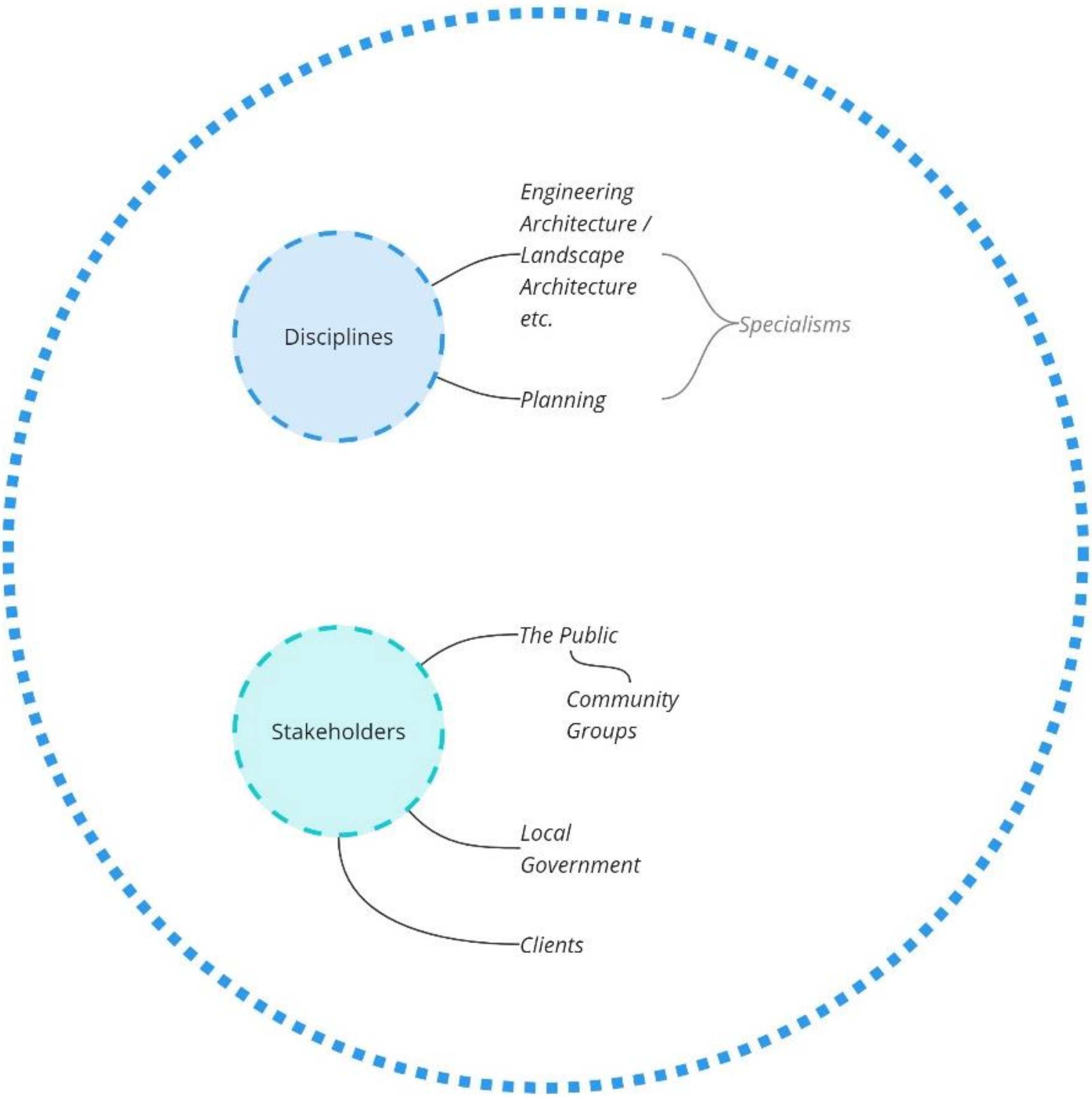


FIGURE 12 - CONCEPTUAL DIAGRAM: RELATIONSHIP OF PEOPLE (AUTHOR)

Collaborative Design Benefits

Collaboration can produce better design decisions (Nelson and Bobbins, 2017) but requires particular skills and shared mindsets. It is important for all collaborators to aim to build trust by respecting the knowledge base of others, listening to each other, and being adaptable to alternative ideas (Nelson and Bobbins, 2017). This requires a shared philosophy for co-creation, allowing all individuals to feel part of the process and be confident in sharing ideas (Teder, 2018).

Woolley et al., (2010) argue that a 'collective intelligence factor' has a large influence on successful collaboration. This is defined as the level of 'social sensitivity' of group members, where the ability to take turns (no dominant member) is a key factor. This was more influential than the average intelligence of group members, or feelings of motivation, satisfaction, or cohesion.

It is not only the type of interaction but also the level of skill and knowledge of collaborators that can vary. This can influence creative capacity, especially as situations and organisational structures become more complex (Parjanen, 2012). This should be embraced to gain practical creative benefits from complex collaborative situations, as the exploration of alternative potential is taken further by dealing with others outside of our experience and mindset (Bowen et al., 2016). This kind of creative mindset is not a given, but needs to be encouraged and supported (Parjanen, 2012).

Faehnle and Tyrväinen (2013) argue that collaborative approaches need to include four key aims, which have built-in participatory values:

- increase the range of knowledge input to the process
- have real meaning to stakeholders
- integrate with wider social systems, governance, and policy
- guide the process towards more sustainable outputs

Collaborative Methods, Processes and Supporting Systems

To facilitate parity in the most effective decision making, it is important for collaborators to be involved at the same time, early on in the process, and for them to be co-located for strong inter-personal connection (Nelson and Bobbins, 2017).

Collaboration is often supported by facilitation and management. Having a skilful facilitator, alongside visual communication approaches, can bring closer understanding amongst culturally divergent groups (Nguyen and Mougenot, 2022). There are conflicting views on the importance of design-planning knowledge vs sider social-context expertise. For example, Salter et al., (2009) argue that facilitation needs experts from specific discipline areas, such as socio-political, methodological, and technological matters. AlWaer and Cooper

(2020), acknowledging a variability of collaborative conditions, indicate that not one approach works in all situations, rather facilitation requires both specific project context knowledge alongside, skill in project management and dealing with the complexity of social relationships. Thus, facilitators need not only to have a diverse range of skills, but also the ability to reduce bias, dominance, and the ability to appreciate specific local needs (AlWaer and Cooper, 2020). Benefits come from incorporating flexibility in designing feedback loops and processes.

In this complex context, the facilitator's role is also influenced (successfully or otherwise) by the supporting technical and social systems that form the mechanisms for collaboration.

> *"Could a group's collective intelligence be increased by, for example, better electronic collaboration tools?" (Woolley et al., 2010)*

Here, virtual collaborative methods have brought benefits to scalability, e.g. allowing more people, time range, etc. and with reduced costs, adding further range of capability to the participation toolkit (Reinwald et al., 2014). Though, virtual interactions can also reduce the quality and subtlety of interactions, such as limiting of nuanced reading of body language. For example, the internet promised networked solutions to such gaps around access and engagement by location, but has not fully replaced real, arguably more meaningful interactions.

The development of collaborative platforms therefore, requires consideration of a wide range of potential collaborators' needs and interests (Imottesjo and Kain, 2022). And, different technological systems can affect different behavioural interactions when applied in the specific project context (Gül, Uzun and Halıcı, 2017).

Here, AlWaer and Cooper, (2020) indicate 5 key principles for consideration in developing collaborative systems (simplified):

1) Scope – reasoning for approach
2) Representation – has a context appropriate inclusive, diversity of stakeholders
3) Stages – identifying pivotal moments for stakeholder involvement
4) Comfort – ensuring a friendly, inclusive social environment to collaborate
5) Influencing Certainty – ensuring tangible, realistic outputs

Urban design projects can be complex and therefore require vast amounts of city-level data layers to be inputted into the design process. Even with increasingly sophisticated and automated digital design software, this can be resource intensive. There is also a still a case to made for analogue work, as experienced humans exploring ideas with pen and paper studies are able to quickly assess the key fundamentals more fluidly (Gil, Duarte and Syntax, 2008).

Barriers and Silos

> *Participatory outcomes are often aspired to, but hard to implement in practice. Involving multiple stakeholders is challenging and requires considerable planning and preparation. (UN Habitat, 2019)*

Stakeholders typically come from very different backgrounds, with different understandings, levels of experience (Alrashed et al., 2015), interests, and varying communication and technical skills (Imottesjo and Kain, 2022; Nguyen and Mougenot, 2022). In addition, stakeholders can vary in their understanding of real-world interrelationships and processes required for things to happen (Alrashed et al., 2015). Adding to this, misalignments can occur in the timing of events, so that requirements for completion of activities are not connected between stakeholders, designers, and other regulatory bodies (Gaudio, Franzato and De Oliveira, 2017). With variance in experience and time, stakeholders may incur different pressures on availability and scope to engage. First, in may take longer for non-experts to undertake tasks with which they are not experienced. They may also experience pressure from other aspects of life, such as their main work or personal commitments (UN Habitat, 2019). Disagreements occurring due to these differences can lead to a lack of consensus in decision-making, and furthermore, it can become unclear how to navigate evolving power imbalances to regain trust. Collaboration in such complex activities demands additional resources and ongoing management (Huxham and Vangen, 2000).

Whilst the organisational systems used to guide collaboration have significant impact on success, the social complexities and disagreements present in real-world contexts are often long-standing and are present no matter which specific collaboration method, process (AlWaer and Cooper, 2020), or technology is used (Saßmannshausen et al., 2021). No matter the collaborative intent, individuals may focus on their discipline concerns and desires (Nelson and Bobbins, 2017) and any changes in stakeholder groups and/or systems mean that progress in collaborative alignments/understanding may lead to repeated activities (Huxham and Vangen, 2000). To resolve this, discipline bodies need to collaborate with each other at early, strategically important stages, to promote collaborative working to avoid reinforcing silo thinking in later, more detail focused activities (Nelson and Bobbins, 2017). The more complex the layers of information in such cases, the more expertise is generally required (Gil, Duarte and Syntax, 2008).

Technology is playing an increasing role in facilitating collaborative processes, from production to management. However, it does bring additional barriers. For non-professionals, particularly marginalised people, there can be reduced access to and experience with high-tech solutions (UN Habitat, 2019).

The following subsection discusses how computing that works within our spatial perception might provide a fundamental benefit to overcoming some of these challenges.

Collaborative Requirements and Challenges

To impart value to a project, individuals need to have meaningful involvement (AlWaer and Cooper, 2020). Even following proclamations of shared aims, it is common for professionals to default to their 'silos', promoting what they know and to underappreciate the value of knowledge from others. Unconsciously or otherwise, professional bodies often reinforce silo mentalities as they define and defend their discipline (Nelson and Bobbins, 2017).

Even where the desire for participatory process is strong, there is still difficulty in its undertaking due to the range of stakeholders' abilities (Alrashed *et al.*, 2015), as well as their competing life issues, level of skill, and understanding of drawings and design methods. This is especially true for public stakeholders and even more so if they are from socio-economically marginalised communities (Nyberg, Newman and Westerberg, 2019).

Often, those facilitating the collaborative process do not have the social skills required to engage in collaboration or to allow them to manage the process. Consciously, they will also often act on bias, manipulating specific agendas, and ignoring others' needs. Therefore, there is some debate whether facilitation should be done by those with a discipline background, or rather as an objective independent facilitator, trained in the skills required for managing an effective collaborative process (AlWaer and Cooper, 2020).

Attempting to define this, Carmona (2014) suggested that stakeholders fall into six categories, whose various desires, motivation, and skills influence with a relation to a hierarchical power structure, from 1-6:

1. Owners of the land and regulatory bodies (e.g. local council)

Who give power to:

2. Designers

Where varying scope may be given to:

3. *Community/local groups,

Proposals are agreed and handed over to:

4. Construction contractors (builders)

Which is inherited by:

5. Maintenance/Management

Who interact with:

6. End users (public)

Collaborative Communication

For design, visual communication is the dominant consideration for success of participation, etc. Areas of urban design analysis, such as understanding character, heritage, and materiality rely heavily on semiotics: the culturally subjective meaning applied to visual artefacts.

> *"This language of the urban makes political hierarchies and cultural values legible", a "complex and stratified meaning, that speaks of the desires, preferences and requirements of those who design, but also of those who live in and pass through the city", each having "sensory perception and cultural experience, depending on their background, tastes and needs", "of the moment and the situation" (Bellentani, Panico and Yoka, 2024a)*

There is a need to represent the three-dimensional urban world around us, and a variety of methods have been developed over many centuries, including plans, sections, perspectives, and axonometry. Until now, these methods have needed to perform as representations of space and its material qualities, which are, in various ways, abstract from the actual, as a subjective representation of the objective space being discussed (Gordon and Manosevitch, 2011). For example. the design 'Plan' drawing, is a geometric representation of the real space scaled to a much smaller paper, top-down, with perspective removed. Even in modern history, the accurately detailed and rendered 3D model, while looking almost as if it were a photo of the real scene, is still most typically viewed as a 2D representation through a flat screen. In this case, we cannot enter the world it presents; there is perceptive abstraction, viewing the scene through a glass window between that world and ours.

Considering the parity of collaborative input, we should also consider the influence of the person guiding visual creations. Visual methods for public consumption are preferred when created via a high degree of quality via training/skill. For example, the traditional hand-sketch street is a perceptive interpretation by a person skilled in both the tactile drawing ability and a deeper understanding of visual qualities like composition, as well as the wider context for the work (Verovšek, Juvančič and Zupančič, 2013). Ultimately, this will include their choice of positioning, their interpretation, and what details they include as a significant influence on the message conveyed. The terms 'a person's perspective', or their 'viewpoint', using the visual as metaphor – or crossover of meaning both for visual and theoretical position. These two uses are not separate but indicate an innate philosophical connection to space in our thought process. Related to this, practitioners of different disciplines will often have differing approaches, expectations, and underlying agendas. Even more so, when compared to stakeholders, there is an even greater disconnect in levels of training, skills, and experience (Rose *et al.*, 2015). This is also true for written and spoken language, for example, in the need to appreciate planning documents and visual portfolios with mixed and/or inter-referenced language ('jargon') and technical or complex drawing typologies, and perhaps within a short timeframe. This can present a significant influence on non-experts' access and willingness to participate (Gaudio, Franzato and De Oliveira, 2017).

Rose et al., (2015) argue that communication methods need to consider this variability of prior knowledge, aiming to bypass barriers such as abstracted, and/or technical conventions (Barndt, 1998) and jargon language (Gaudio, Franzato and De Oliveira, 2017). Similarly, 'Silo''s thinking often creates biases towards specific practices or aims (Cuthbert, 2007, 2010; Nelson and Bobbins, 2017).

> *Developing research methods, should consider "representation, discourse, language, text, semiotics or symbolism", "meanings that are conscious results of social construction" (Dovey, 2023b)*

With a diverse range of potential collaborators, the success of collaboration largely comes down to long- and short-term relationships between people. This arises through explicit and non-verbalised agreements within design, as a 'Perception-in-Action process' (Tschimmel, 2011). This is a complex and variable matter, where success relies heavily on management and facilitation of overall process within each specific event. Success also relates to the methods used to communicate, which form a collaborative interface (Luyet *et al.*, 2012). The aim is to manage communication between the range of participants and contextual information (project data, files, outputs: drawings, writing, etc.). How this is done is subject to the participatory approach, and significantly, the level of participation (Arnstein, 1969). Therefore, no one solution has been presented, but rather a range of visual and writing methods that support different stages and aims. Methods may have a strategic or specific focus and may be in complimentary alignment or directly competing.

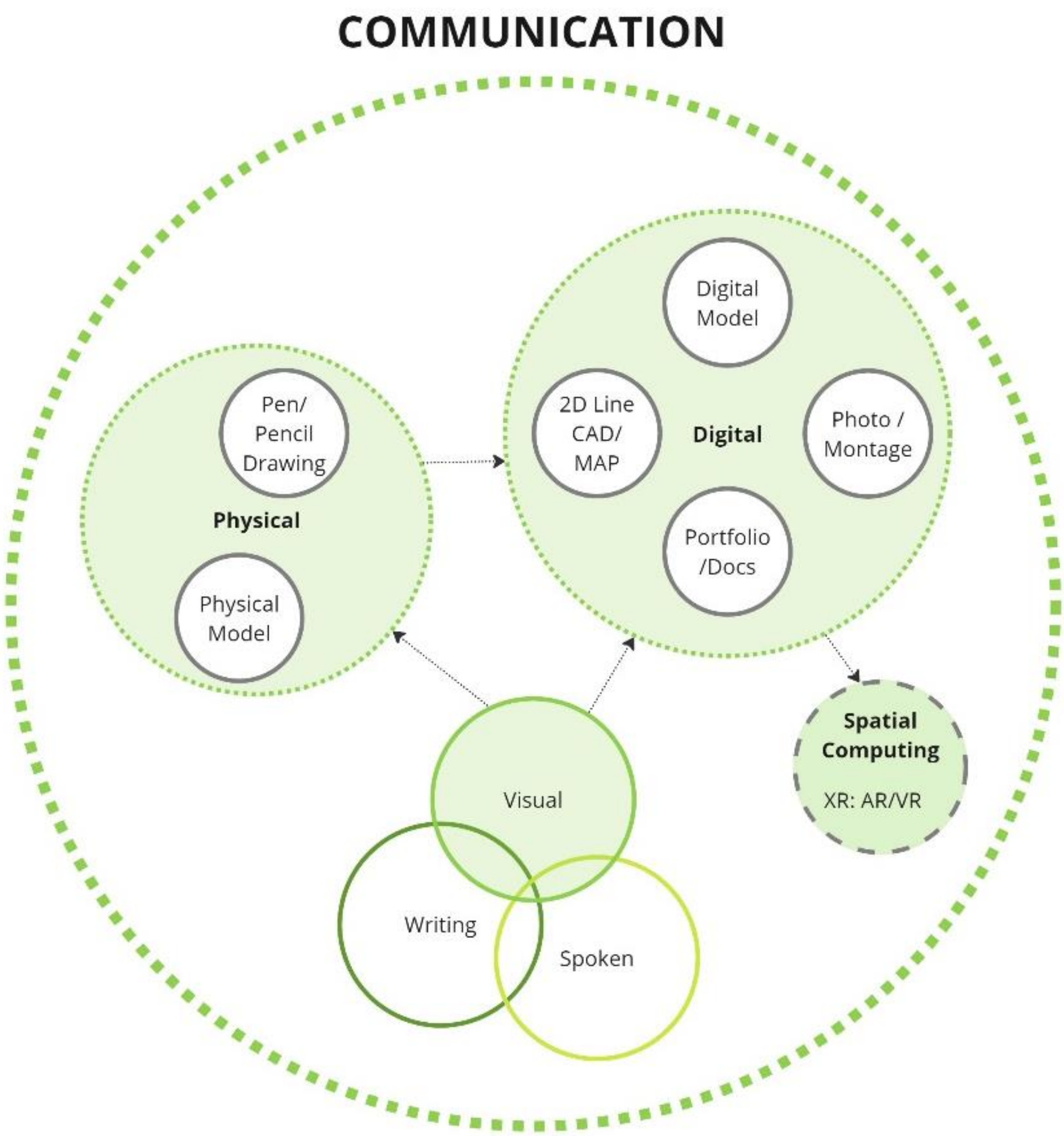


FIGURE 13 - CONCEPTUAL DIAGRAM: RELATIONSHIP OF COMMUNICATION (AUTHOR)

Urban Design as Spatial Communication

Different communication methods provide different understandings of the subject to be communicated. Each method has inherent strengths and weaknesses, which both facilitate and mask specific areas of understanding. In trying to communicate design ideas as a whole, communication types tend to be used in combination; for example, a design document page may have photos, sketches, plans/maps, sections, and perspectives, which may be supported by annotation text (Meeda, Parkyn and Walton, 2007; Farrelly, 2011). This may also be verbally presented in person to ensure that the scope of the intended meaning is fully asserted.

Urban design sits on a loose spectrum that ties the large scale: urban planning to local scale: architecture. It functions as a strategic design approach (of planning) and has far less focus on the detail or construction as for example, compared to architecture. It therefore tends to be represented using more diagrammatic, conceptual, or deliberately simplified visual outputs (Cozzolino *et al.*, 2020). Methods are often combined to highlight the integration between tangible (physical) and intangible (social) aims and outputs. Aligned to this are the specific aims of strategic, collaborative, participatory. There is some variance to specific stages or approaches. Urban design is situated at the stage of process largely understood as a combination of spatial form and function. And thus, has a focus on visual communication. In contrast, urban planning has a primary focus on writing, perhaps supported by some statistical data and mapping (Urban Design Group, 2019; Cozzolino *et al.*, 2020).

TABLE 2 - BROAD COMMUNICATION TYPES IN URBAN DESIGN/URBAN RESEARCH

Broad Type	Specific Type	Established/Standard Format
Visualisation	3D model	• Physical Model - Plasticine, paper, cardboard • Digital Model – 3D CAD • Physical From Digital laser cut, 3d forming
	2D image	Printed or on screen, shown at scales: • Plan and Sections • 2D (of 3D) Isometric/Axonometric • Perspective View • Photograph, Montages
	Video - Film / Animation	Video recorder, editing. Screen / Projector
Writing	Annotation	Physical Notepad, Post-it
	Planning, Brief writing	Report, Planning Statement, Website Portal
Portfolio	Collated	Combination of visual and text, Publication Design
Spoken	Audio Capture	Device capture and playback: Dictaphone / Mobile Device ('Phone) (MD) and speaker system
ALL	Management	Collaboration Manager Role and/ Software

Summarised (Farrelly, 2011; Lucas, 2016)

The increasing influence and realism of digital modelling and manipulation can present conceptual proposals with immersion, realism, and/or experiential interaction with design proposals (Nielsen, Delman and Lossings, 2005; Bishop, 2011). For example, elements of natural lighting, changing weather effects, and interactions with artificially intelligent characters.

However, high-tech solutions can present barriers with regard to digital literacy or lack of access (hardware, internet, etc.), a need for "bridging the digital divide" (Nyberg, Newman and Westerberg, 2019). Specific urban design software, such as CityCAD (2024), is highly controlled and precise, the conceptual stage of design may still be best worked on by more fluid exploration with "traditional pen and paper process" (Gil, Duarte and Syntax, 2008). In these ways, the requirements for design communication are oriented towards professionals and are less accessible to a broader audience (Alrashed *et al.*, 2015).

Despite the enormous extent and dominance of digital means of design communication, there are still key tactile benefits to hand drawing for tasks within the early design process, where nuance and brain-hand interaction speed. Hand drawing relates directly to an individual's specific tactile interaction; manipulating the physical drawing equipment is related to the physical properties of the drawing medium. In general, there are still strong benefits:

- Unique Character – "the impression of inhabitation and liveability… achieved by expressive hand drawings" (Meeda, Parkyn and Walton, 2007)
- Speed of conceptual development, feedback loop, an essential skill of designers (Van Den Toorn and Guney, 2011)
- Situational freedom, access 'Ad-hoc process' (Ostwald, 2017)
- Integrated, deep process of framing and selecting an intended perspective/communicative meaning (Štefancová *et al.*, 2020)

To some extent, this can be replicated or instantly digitised by digital pens and drawing tablets (Calixte and Leclercq, 2017), which bring unlimited potential styles and settings to one device, and are increasingly accurate/tactile, especially at the higher end of the price spectrum (for example, Wacom, XP-Pen, Apple Pencil, Microsoft Surface Slim Pen). Despite these benefits, there are still gaps between real and digital interactions. By comparison, digital lacks the full tactile range of properties, and these gaps vary between different technological approaches and in handling sensory variation of surface material types (Riche *et al.*, 2017).

2.3 Spatial Computing

"Augmented Reality (AR) and Virtual Reality (VR) are technologies of utmost importance for the Architecture, Engineering and Construction (AEC) sectors as the built environment is intrinsically associated to three-dimensional (3D) space" (Delgado, Oyedele, Demian, et al., 2020)

Spatial Computing for Spatial Design

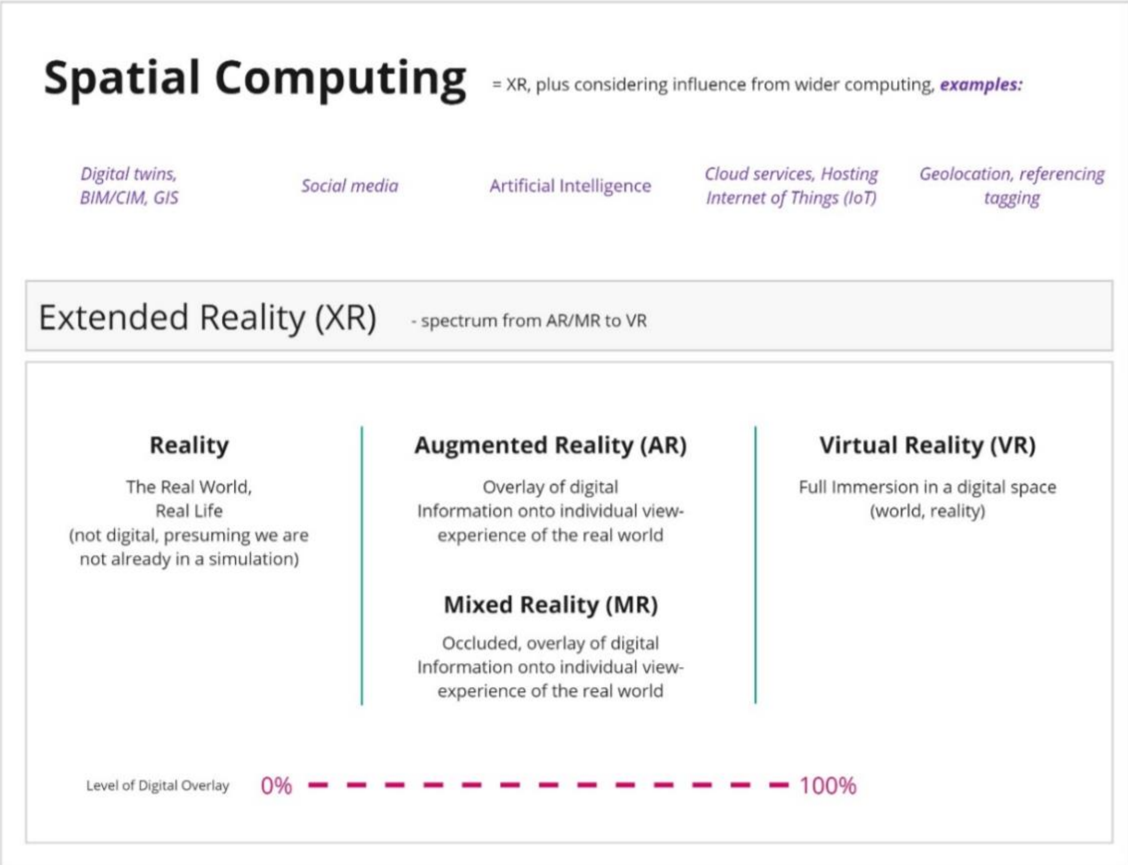
As established in the previous sections, Urban Design spans several disciplines whose remit is spatial design. It is not a leap of imagination/expectation to expect that the integration of digital communication as a more direct experience with spaces and of spaces will be of use to these spatial disciplines, where the real and virtual converge (Seichter, 2007b; Wang *et al.*, 2013; Delgado, Oyedele, Demian, *et al.*, 2020).

This integration of '*any*' digital information within our spatial realm is defined here as spatial computing, as digital overlay or immersion of our world view, audio-visual sensory perception (and therefore daily cognitive experience). The term 'spatial computing' (SC) is chosen here as an intentionally broad definition. This goes beyond 'Extended Reality' (or XR), which itself defines a combination: of Augmented to Virtual Reality (AR-VR) as a 'Reality to Virtuality Continuum' (Wang, 2009).

Spatial computing is intended as a broadest umbrella term, aligning XR technologies with <u>any other</u> existing and/or potential digital technology that integrates with, or represents spatial conditions. Some examples where we might currently expect useful alignments/integrations for urban design are geographic information systems (GiS), cloud computing, and smart technologies, to name a few broad categories. With SC, our sensory perception of the world can be overlaid with varying levels of digital information, from minor to major quantities of overlay. This can vary both in terms of the types and amounts of data, as a level of immersion, and is subject to qualities such as interface design, responsiveness, and comfort of the system.

The level of overlay can vary from a single to a multi-object overlay, as presented by Augmented and Mixed Reality (AR/MR), to an entire perceptive immersion in a virtual digital space and environment, as presented by virtual reality (VR). As an idea and interface, this can elicit for each user the perception of cognitive presence either in a virtual space and/or of digital artefacts being perceived as believably integrated into a user's real-world view of space as level of ecological validity. These are not absolute categories either, but sit along a spectrum between these extents (Stanney, 2002; Seichter, 2007b; Sun *et al.*, 2015; Chen *et al.*, 2017; Gironacci, Mc-Call and Tamisier, 2017; Ergun *et al.*, 2019; Hong *et al.*, 2019; Šašinka *et al.*, 2019)

Figure 14 - Terminology Spectrum – Hardware Types. Summarised (Author)



Benefits to Perception of Space, via Immersion & Presence

"Where are my legs?" (Šašinka et al., 2019)

The perceived realness of a virtual aspect of spatial computing is defined by the 'level of presence' and 'level of immersion'. Whilst users are, of course, still physically present in what they feel as an objective world, they can also feel being present, with, or in virtual objects and space (Šašinka *et al.*, 2019) due to feeling like they are sensorially immersed in that experience. Though this immersive effect is discussed in terms of levels of experience, rather than something really seen; a recognition of being somewhat fabricated (Portman, Natapov and Fisher-Gewirtzman, 2015).

The effect of perceptive immersion in digital information can be so strong that the removal of virtual elements, that is, taking off a VR headset, can produce cognitive confusion (Šašinka *et al.*, 2019). Though Seichter and Schnabel (2005), argued that spatial immersion may never feel entirely 'real', as: the *"complexity of the social, political and sensorial richness is unlikely to be simulated",* the quality of simulation has moved on a long way since 2005. As Maffei *et al.* (2016) found, in terms of believability of perspective experience, there can now be great similarity when comparing audio and visual effects in terms of real vs. virtual immersion. Aligned to this, we can see gradual merging of physical and digital spaces, as highly popular AR games, such as Pokémon go have shown (Potts, Jacka and Yee, 2017). This might bring increasing benefits to the creation and understanding of design, where virtual objects and spaces presented in such ways allow greater understanding by laypersons (UN Habitat, 2019).

Combined with participatory approaches, integration of various technologies to create urban design and collaborative possibilities might provide significant skill gains, for example, with spatial research and interaction tasks (Fonseca *et al.*, 2014; Fonseca, Redondo and Villagrasa, 2015; Fonseca Escudero *et al.*, 2017). This also needs consideration beyond current uses, which may define or redefine the intended meaning of the terms we use.

Navigating diverse Terminology and Interpretations

Reviewing academic and practice references related to areas of spatial computing has highlighted a diverse and inconsistent use of terminology and interpretations. This is despite discussion of the confusion and reduced accessibility that this inconsistency causes (Rauschnabel *et al.*, 2022), as well as numerous attempts to explain it to the general public (Intel Corporation, 2024). These terms have not yet been fully rationalised in the tech industry, let alone in the academic literature or areas of design practice. They often feel competitive with each other and are used by different technology companies to define their approach.

Although there are others, the key terms currently used are as follows:

A. Specific technological approaches and outcomes
    - *Virtual Reality (VR) – simulation, elicits feeling of being inside a virtual environment*
    - *Augmented Reality (AR) – Virtual objects overlaid into sensory perception*
    - *Mixed Reality (MR) – a more integrated version of AR or between AR and VR.*

B. A spectrum of approaches: with conceptual/theoretical connections across specific technologies
    a. Extended Reality (XR), Immersive Computing, Immersive Technologies - spectrum
    b. Spatial Computing – spectrum plus other digital data input

While the choice of terminology is not pertinent to the research questions and it seems will be decided in time by wider culture, it has been important to understand this very inconsistent landscape of terms to be able to successfully navigate existing knowledge on the subject. Though sharing similarity of concept, technological, and experiential approaches, these terms are not consistently used, leading to interpretations that are sometimes synonymous, or not-entirely synonymous, but also have overlap.

"it is hard to find current interdisciplinary research aimed at improving VR techniques or helping define across disciplines, what we mean by "virtual" or even by "reality"."
(Portman, Natapov and Fisher-Gewirtzman, 2015)

Why use the term" Spatial Computing'?

'The use of 'spatial computing' in this research is a direct statement that the effects and specific capabilities (of being spatial) should be of more interest to UD than the specific technology used, that its great potential value lies in a more diverse omni uses as a spatial interface for design, not only specific, quite limited use cases. This also aligns with the expectation that AR-MR-VR are increasingly moving towards technological convergence, where subsets start to merge capabilities until there are fewer, but each more capable systems. This started to occur fundamentally during the timeline of this project. For example with devices that are, or were recently, considered as VR, through improvements to cameras and tracking, became increasingly capable also as AR/MR devices and are marketed as such, for example, "Meta Quest 3: mixed reality VR headset" (Meta, 2024). Hence, using 'SC' is an argument that increasing discussion is needed on broader wealth of potential applications that might be helpful for Urban Design, for example, incorporating GiS, Cloud Computing, Artificial intelligence (Ai) and so on.

The term spatial computing has been brought into more popular use recently, due to marketing activity, firstly by Magic Leap Inc. (2020) and more notably in terms of market popularity, Apple: in respect of their Vision Pro 'spatial computer' headset (Apple.inc, 2023). However, the term spatial computing is not new. It has been used to describe the organisation of computer logic for image analysis (Hawkins and Munsey, 1963), geo-spatial (context applied) data in Geographic Information Systems (GIS) research (Reeve, 1985; Wilsher *et al.*, 1993), and specific computing methods (for example Ai) to aid the spatial design process in architecture and design (Bhatt and Freksa, 2015), and for immersive technologies (e.g. AR/VR), as often cited in popular writing (grey sources), as the "human interaction with a machine in which the machine retains and manipulates referents to real objects and spaces" in computer science (Greenwold, 2003).

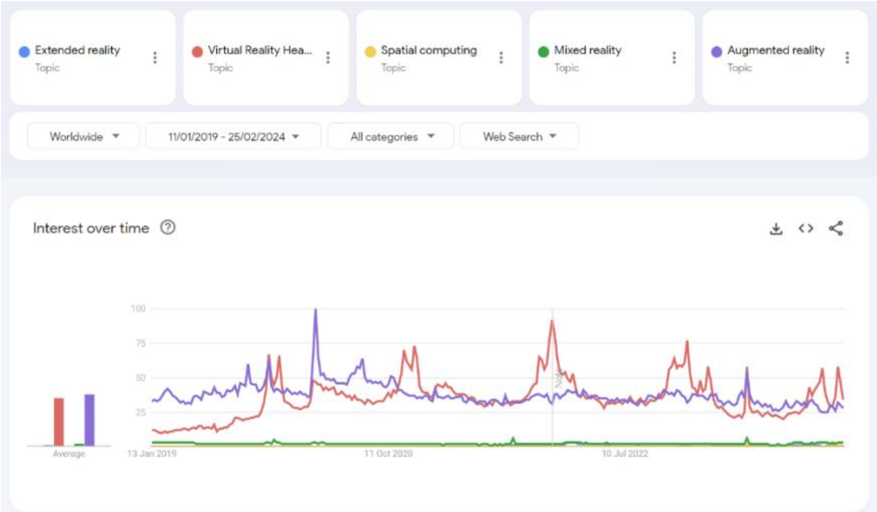


FIGURE 15 - COMPARISON OF TERMS USING PUBLICLY AVAILABLE GOOGLE TRENDS SEARCH DATA

Using the search function of the University of Sheffield Starplus library database see below table 2, the term spatial computing was compared to other key terminology, with the number of search results returned taken as general indication of level of use. The terms Virtual and Augmented Reality are most used, with all other terms being much less used. As indicated in the number of search results, spatial computing is the least common usage in research. Whilst this could be interpreted as a reason to not use the term, it is felt that on the contrary, this is an indication of a reduced understanding and certainty at the strategic level, on how all these technologies conceptually come together. In other words, it is an under-studied area. This case is not only for the term spatial computing. All terms that define an integrated (strategic) spectrum of AR to MR and VR are used far less: Extended Reality, Immersive Technologies, and spatial computing.

As Tomkins and Lange, (2021) indicate, the reason for wider use of the terms AR, VR, is that "applications tend to be limited to a single-use case, due to the complexity of adapting in-situ visualisations to different environments and topographies". However, with technologies becoming increasingly developed and accessible, we are starting to look more at the strategic integration of capabilities and need to use appropriate terminology to represent this more holistic aim.

TABLE 3 - SEARCH TERMINOLOGY, NUMERICAL

Phrase Search 'exact, within full text	StarPlus Total	StarPlus, AND exact 'Urban Design'	StarPlus + *'Beyond Library Collection'*
Virtual Reality	261, 107	1617	525,933
Augmented Reality	103,500	656	262,224
Mixed Reality	21,758	198	52,624
Extended Reality	4943	44	12,986
Immersive Technologies	5714	65	14,242
spatial computing	1264	24	3385

The University of Sheffield Star Plus 25.02/2024

Hardware terminology

A spectrum of terms was also used for specific hardware types. Milovanovic et al. (2017), collated the key terms using corpus analysis of literature, which are simplified here from the rather complex acronyms and terms used in the source.

Extended Reality – key types:

1. VR
    - Head-Mounted Display (VR HMD)
    - Surround-Screen based VR (i.e. 180- or 360-degree large displays)
2. AR – Augmented Reality–key types
    - Tangible interface & Surface AR – AR Desktop, Table
    - Head Mounted Display (AR HMD)
    - Smart Devices (Phones, Tablets)

Separate Systems, or Convergence?

Current hardware for Augmented and Virtual Reality is still mostly separate, each with broad and specific implementations, technical considerations, strengths, and limitations. Evaluating the opinion of a range of professionals across areas of practice, Rauschnabel et al. (2022) argue that AR and VR are not only different systems, but fundamentally different experiences. With complete immersion in a digital world, VR is useful for understanding design ideas, whereas the digital overlay of AR allows greater understanding of the live context* and its lively sights, sounds, and smells (Tunçer, 2020) (*for urban design: the 'sense of place').

Until recent releases of more powerful untethered headsets (such as Quest 1-3 (Meta, 2024)) high quality design rendering relied greatly on supporting hardware (PCs). This was costly and immobile giving a clear advantage to AR for live, in-situ applications (Gill and Lange, 2015). AR and VR approaches have specific technological benefits, conflicts as well as resultant compromises. There has been some recent advancement towards convergence of AR-VR. The use of the term 'mixed reality' (MR) is often used to indicate increasing integration/interaction with the physical world, blending the benefits of AR and VR' (Intel Corporation, 2024).

Convergence, in the form of an integrated interface with diverse capabilities, would bring holistic benefits to urban design. This was demonstrated by Ishii et al. (2002), where a diverse range of methods, as typical to the design process, from sketching, physical model making, to computer rendering, enabled users to see relationships between "physical, social, and dynamic factors" within one visual interactive space. When (time) separated though, these processes required separate skill and thought, presenting incompatibilities and distractions from the core design process. Grassi and Klein (2016) furthered this kind of approach to consider the wider social aspect of design management, with an AR system that allowed integrated interface for managing and exchanging stakeholder comments.

For example, SC (and AR, VR., etc.) is typically presented as meaning technologies which allow digital integration into an individual's perspective view (Nisha, 2019), but can also be used in definitions of GIS data, as spatially mapped (Xie et al., 2018). These separate uses of the terms might seem distinct and present a conflict, but from an urban design perspective, both meanings are not only useful, but are combined in our broader understanding of 'spatial information'. For example, both plan and perspective are separately useful ways to look at space, i.e. presenting strategic dimensional (e.g. map), or human contextual view (e.g. photo) (Farrelly, 2011).

Foundational systems, aligned systems, and the confluence of technological ideas

As defined earlier, the use of the term spatial computing implies the alignment of extended reality technologies to other areas of computing, essentially spatialising any type of computing. In addition, as spatial computing has evolved from computing more generally, it utilises the conceptual and technological developments of other digital technologies as the foundation or aligned capabilities and conceptual ideas. It is important to understand these in terms of their prototype and asynchronous impact. Despite still feeling new, studies since the 1980s have provided empirical research into the use of various prototypes for digital AR and VR systems as a way to potentially facilitate specific contexts and actions of design collaboration (Frazer, 2010). The following briefly discusses key aligned ideas/systems which have been presented in the research literature as having a significant impact:

Computer Visualisation - until relatively recently, rendered computer visualisations (generally, not necessarily AR/VR) were considered an expensive addition to the design process, requiring specialist technology as a means to convince clients of the final design product (Lange, 2001), but since then have quickly developed to become a ubiquitous tool (Lange, 2011; Koutsabasis et al., 2012).

Mobile, Networked, Integration - mobile AR, is able to *"give us a new understanding of location, orientation, flow of information, ownership of the data, and the reality itself"* (Goudarznia, Pietsch and Krug, 2017). It might thus increasingly provide an in-situ interface that can integrate and manage communications and interactions in live, complex design processes, as within the real, simultaneous and shared 3D environment of urban design (Gordon and Manosevitch, 2011). While dedicated VR labs have the advantage of high end-graphics, the viewer is spatially detached from the real site context (Gill and Lange, 2015). Thus, the increasing convergence, accessibility, mobility, and networking of these intelligent technologies and their integration into the urban fabric (the 'smart city'), increasing potential for greater efficiencies and transformed interactive possibilities (Bibri, 2018).

Smartphones -The ubiquitous uptake and demand for smartphones has meant that AR has become increasingly accessible with increasing capabilities (Fonseca Escudero *et al.*, 2017). The in-situ visualisation capability of mobile devices (smartphone, tablet) showing 3D models, either aligned to views or using AR, were helpful in supporting users spatial, situational understanding of design proposals (Bilge, Hehl-Lange and Lange, 2016)

3D worlds ('Metaverse') and 'Game Space' - Digital 3D virtual worlds allow unrealistic situations that might actually be helpful, for example, flying around in the 3D space to aid in the efficiency of rotating and moving around an object or space being developed. Compared to non-3D digital interfaces, being able to communicate in 3D space has been shown to better encourage users to communicate (Koutsabasis *et al.*, 2012).

Geographical Information Systems, Building/City Information Modelling (GIS, BIM/CIM) - Jiang and Thill (2015) argue that the diversity of input through crowdsourced geographical information systems allows for deeper, with greater scope of socio-economic understanding and less bias. (Speranza 2016) notes that this wealth of foundational data, which design teams then use (mapping, reports, sites, and precedent photos), is removed from the experience of the place. Barndt (1998) argues that more data do not necessarily persuade people of certain design/planning decisions. Within building/city information modelling (BIM/CIM) systems, spatial computingcombining BIM and AR has been shown to reduce cognitive 'workload' by increasing efficiency and reducing errors (Chu, Matthews and Love, 2018).

Tangible User Interface (TUI) - with a TUI, users can move physical objects to create digital effects (interactions), which have shown a general facilitation to the speed and level of collaboration interactions in comparison to traditional methods for planning (Alrashed et al., 2015).

CAVE and Projection Mapping - significant development of spatial computingas an idea has come from interactive, room-based systems that use a 360 °array of monitors: Cave automatic virtual environment, or 'CAVE' (Havig, McIntire and Geiselman, 2011). or projection-mapping systems. Both approaches display in real-physical space and therefore facilitate a shared space multiuser experience (i.e. with real life, spoken communication) and are often capable of very high visual resolution (Salter et al., 2009; Calixte and Leclercq, 2017; Krietemeyer, 2017). When compared to mobile and head-mounted XR, a major drawback of these systems is that they require a fixed place and complex setup. For example, describing a projection mapping setup, Calixte and Leclercq (2017) define three elements that are needed: the projection system, the projector, and video outputs; the visual management system, a computer with specific software and a surface, and the object to which the content is mapped (displayed); even minor physical movement of any of these components will misalign and break the visual display.

Chapter Summary

To deal with the complexity of the urban context, as both physical and social human environment and design, it is necessary to account for a diverse variety of methods and approaches. This complexity leads to transdisciplinary approaches and collaborative work. Collaboration presents several challenges. Particularly important is the need for good communication and facilitation of the design process, where many barriers present themselves. spatial computing is emerging to potentially open better access to design by presenting design ideas within a user's direct spatial perspective viewpoint. The following section describes how this problem/opportunity is understood and approached from a philosophical perspective.

> *"The creation of virtual environments gives us an opportunity to replicate, construct, deconstruct, embellish and analyze complex real-life images and the human experiences that accompany them"* (Portman, Natapov and Fisher-Gewirtzman, 2015)

2.4 Philosophical Basis of the Research

This short section defines the philosophical underpinnings of this research. Broadly, this sits between an understanding of the research themes as relating to understanding and design of 'Places': as a physical, and social reality - as discussed in the previous chapter. As such, the core values and philosophical debates which define a foundation for the methodological and evaluative decisions that follow relate to 'The Urban' (context) to, Urban Design, Collaboration, and spatial computing. It is not an aim of the study to fundamentally critique philosophical principles; this section provides a brief narrative to underpin the methodological and evaluative decisions that follow.

Though deepening the philosophical aims of research can further abstract focus from practical decisions, transparency and collaboration in research can be improved by discussion of our underlying philosophical position. And, there can be no data, or methods actually free of theoretical perspective (Alvesson and Sköldberg, 2009). The ontological belief and epistemological lens used in research influences decision making, methods, direction, and evaluation of research, whether identified or hidden (Creswell, 2013).

Our methods for knowing (epistemology) are greatly based on the underlying belief (ontology) (Fryer, 2022) and rationale (Steinmetz, 1998).

- Ontology - study of 'being' (Reality)
- Epistemology - study of ways and methods for knowing this reality

Between positivist and interpretivist interpretations in Urban Design

Urban design is a contested field (Marshall, 2012; Dovey and Pafka, 2015), with proponents taking stances between positivist and interpretivist camps. The urban has a multitude of physical and social layers (Lang, 2005) and design processes attempt to integrate context, time, place, and perception-dependent viewpoints (Hack and Canto, 1984). As designers, we admit that our ideas are corrigible and open to revision through further iterative input processes (reflexive) (Alvesson and Sköldberg, 2009; Archer, 2009). The sides of debate around the nature of urban design, as discussed in chapter 2.1, are based in fundamentally different ontological belief systems, e.g. as taking a more Positivist or Interpretivist stance:

- Positivist (Realist): an objective reality with deterministic rules and universal truths, understood via scientific method and observed via empirical measurable facts.
- Interpretivist (Constructivist): reality is subject to individual perception, with data focusing on subjective personal and cultural factors.

Research Focus

Urban design research requires an ontological frame that considers both sides of physical and social reality. Hence, two key ideas are combined:

- Assemblage theory - emergent relationships between things as a process
- Critical Realism – seeking to understanding deeper causes for certain effects (mechanisms: including affordances)

These theories have been selected with the aim of understanding the research data more deeply, as context-laden, and within highly dynamic 'real-world' processes. They are understood as in a constant state of change and/or forming (temporary) organised structures with defined elements that present potential to cause effects (Rutzou and Elder-Vass, 2019).

> *"The purpose of scientific activity no longer stands out as a statistical putting together of surface phenomena in an observed reality. Rather the important thing becomes to conceive this reality as an expression for, or a sign of, deeper-lying processes"*
>
> *(Alvesson and Sköldberg, 2009)*

Assemblage

Assemblage is a meta-theory that describes the emergent processes that form social structures. The world is a changeable, adaptable network, with clusters of things that connect to other things, and which constantly emerge, coalesce, collapse, etc., as time progresses (Deleuze and Guattari, 1987) (D+G). Assemblage is illustrated by the analogous image of a rhizomic structure, as is the habit rootstock of certain plants. This describes physical and social structures that do not branch back to one point (unlike most obviously a tree), but can grow and expand, or contract in any direction in a 3d space of real possibilities. This is also identified as analogous to the creative process, or at least of things having a *capacity* to happen, whether they actually happen, or not. In this way, D+G argue that realities are not limited to being cloned representations of past ideas, but are part of an open system, not fixed or defined by rules (no universal truths).

DeLanada, who built from the work of D+G, clarifies what he sees as specific 'properties and capacities' of assemblages (DeLanda, 2016). The first key principle is of variable levels of assemblage, or, as a 'control knob'. On the high input, there is a highly fixed, stable, and unified assemblage; on the low input, there is a chaotic, highly mobile, novel, and destabilised assemblage (DeLanda, 2016; Ball, 2018). De Landa (2011) describes a non-linear process: a dynamic system, not governed by rules, but by differences in the intensity of matter or ideas (e.g. osmosis, gravity, political campaigns). It is argued that such imbalances keep life moving, with the larger the difference, the more life, more chaos. In such systems, there is capacity to cause effects, but they effects are only actualised in a contextually appropriate events. In addition, causality cannot always be directly observed. Therefore, the ideas of assemblage present not only the empirical data points, but also the connections and relationships between types. This offers a way to see the dataset, not as wholly representing a universal truth for pure, objective analysis, but as a process, of 'flux and flow' (Deleuze and Guattari, 2019)). These interactions and a multiplicity of capabilities, need contextually deep evaluation, via open-minded exploration, and specifically of' de-familiarisation, to avoid entrenching developing research ideas within pre-established design/academic practice ideas [see 1.6, Reflection on background experience].

Importantly it is Delanda's description of stable and unified assemblages ('high' position of a control knob), which indicate certain states of being that might determine underlying realities, as causes of specific effects (via mechanisms), as follows.

Critical Realism

> *"The notion of causality is central to the world of scientific investigation"*
>
> *(Raduescu and Vessey, 2008)*

Critical Realism (CR) integrates elements of positivist and interpretivist thinking, as integrated rather than 'left in a state of continual polarised debate' (Bhaskar, 2020). It is the belief in a positivist: deterministic universe, as an absolute reality (ontology), but is critical of our ability to know it, as being always subject to our theoretical, social lens (subjective, epistemology).

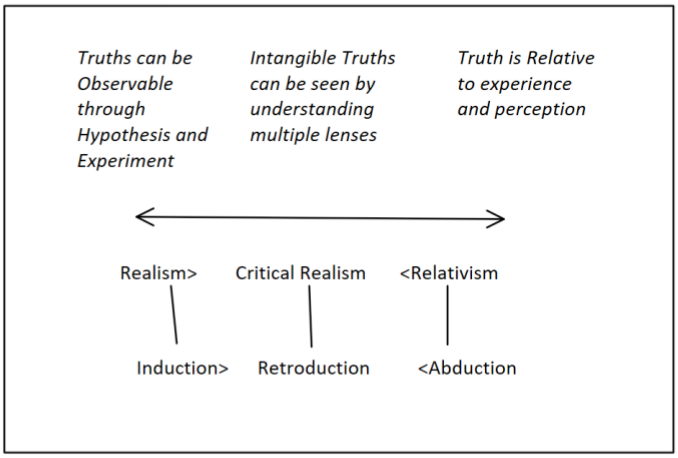


FIGURE 16 - SUMMARISED SPECTRUM (MEYER AND LUNNAY, 2013)

Critical Realism posits that we should be critical of our ability to fully interpret reality. Whilst the world we inhabit is real, it is an endless, multilayered, social, and physical complexity, and our various observational limits, cannot ever entirely measure it in the sense of an all-encompassing knowledge. Bhaskar (2008) calls this the epistemic fallacy (one lens does not capture the whole truth).

The middle-ground of CR '2.' below is relative to the traditional polarised paradigms, as presented <u>with critique underlined</u> by Fryer (2022):

1. Positivist: Realist-Objectivist – seeks universal laws, shallow causation (<u>which are not universal</u>)

2. Critical Realist: Realist-Subjectivist – looks for causes, structure, impact (asks 'why?')

3. Interpretivist Constructivist/Irrealist–Subjectivist methods, narrative meaning: <u>endless debate</u>

In CR, reality is seen as a 'stratified ontology' (Bhaskar, 2020), which considers three domains or levels of reality:

i. Empirical – what we can observe and measure
ii. Actual – deeper contextual interpretation of that reality
iii. Real – reality itself, which is not entirely knowable but can be increasingly approximated by incorporating multiple lenses of iterative research over time (a best estimate).

'Causal Mechanisms'

CR aims to understand 'causal mechanisms', which are mechanistic combinations of factors that work in tandem to produce certain effects if the conditions are right. That is, they have the capacity to effect but may not without a person, or equivalent agent to action them. When defined, mechanisms are only ever explanatory, as 'best guess' of an indicative meaning. For critical realists, mechanisms are (at least) subject to different interpretations because they sit within the deeper layers of reality which are more complex than can be understood by one epistemological lens.

> *"A causal mechanism is (i) a particular configuration of conditions and processes that (ii) always, or normally, leads from one set of conditions to an outcome (iii) through the properties and powers of the events and entities in the domain of concern" (Little, 2011)*

The intention of the word mechanism in CR can be both literal, meaning an actual physical, or technical mechanistic series of interactions that result in an effect. It can also be analogous within a social system, for example, where a series of situational contexts, as well as thoughts and actions, combine to produce a particular effect.

Specific parts and combinations form an overall mechanism that *can* cause a specific effect. For example:

- Mechanics: cogs, wheels, etc.

- Digital – computer coding families and functions, over 'run time'
- Social – the macro and microstructure of an organisation or business, alongside individual life experience

Example Mechanism: *"The market mechanism, explains how the price of a good is caused by supply and demand…while we may observe buyers and sellers agreeing on prices and volumes…the mechanism is unobservable/ non-deterministic, but "its effects are observed and the "explanation of how the mechanism works is generalizable." (Bygstad, Munkvold and Volkoff, 2016)*

Combining Assemblage and Critical Realism

Assemblage poses a reality without underlying structural rules, where change is derived from the difference in intensity of 'things' (catch all), as fuelled by the tension between chaos and order (*A Materialist History of Cities*, 2011). CR does not indicate the opposite but implies a search to understand an unseeable reality that might have underlying structural rules that we cannot fully see. Both refer to the concept of emergence. CR refers to systems that, in assemblage terms, could be considered more stable, are temporary over longer time. Delanda's idea of assemblage control knob and the CR idea of an underlying mechanism for change, are both seeking understanding of the forces for change, for certain things having *Capability* to happen

- Assemblage Of: "difference, fluidity and process"
- Critical Realism Of: stability and structure
  (Rutzou and Elder-Vass, 2019)

To put these theories into practical frames of research design: Assemblage appreciates that many of these systems and processes in new technology are emergent (not totally fixed, fluid). This enables a way to express the overall relationships between different fields and organisational systems, as well as the change of certain fields and conditions over the course of the events in this research. Perhaps:

- Urban Design, somewhat stable, though not entirely static as debates are ongoing and practice continually updated
- Spatial Computing, still quite chaotic 'emergent', with increasingly stabilised elements.

Critical Realism is used for understanding the potential structural mechanisms that might produce certain outcomes as a process of evaluation for interpreting and making use of data points, as discussed next.

Affordance as mechanism

It has been considered that decision-making, public participation, and the design process (see research questions) are broad mechanisms. However, these do not describe fixed mechanics but will have exactly unique examples occurring for every new event and/or action that is undertaken – they are complex (and not entirely observable). In addition, in terms of navigating the design of real, virtual, and increasingly hybrid worlds, we can also understand that specific affordances act as components of broader mechanisms.

Bygstad, Munkvold, and Volkoff (2016) define affordances as "a subset of the mechanisms", as the 'potential for user action, which creates an outcome'. For technology (e.g. spatial computing), affordances are present as key possibilities between the relationship between the technology and the user. Each user has personal capability to actualise that affordance, which is also influenced by the wider organisational context in which they are working: as 'techno-organisational' conditions, that "enable or constrain the actualization of the affordance".

> *Technology: "a technical object is a complex assemblage of many parts", "an actor, an individual, or "a collection of individuals". "The relation between technology and an actor will be associated with a variety of affordances at various levels"*

The design, or form and structure of natural or designed arrangement of environment, systems and technologies, 'afford' certain uses (affordances). Therefore, influenced by and subject to end-user (actors) decisions and abilities in relation to the social conditions within which they are taking place. Mechanisms (as understood in CR) are unobservable: they are not determined but have the potential to occur, and as such, are tricky to understand and interpret. Bugstad et al. argue and demonstrate how affordances can be defined and, therefore, used to appreciate likely mechanisms more easily. From a specific affordance and in combination/contrasted with other affordances, potential underlying causes can be estimated.

Applied to the analysis of data, Bugstad et al. proposed several steps, as summarised:

1. Events and Issues: define case context.
2. Key entities: define, for example, individuals, technologies.
3. Theoretical re-description – abstract the case (make non-specific), appreciate a wider perspective.
4. Retroduction: postulating on the mechanisms.
   a) Concrete Outcomes – achieved, or could be, from use of the technology.
   b) Analysis of Entities – relationship between people and technical (e.g. interface).
   c) Candidate affordances – arising from people and technical relationships.
   d) Stimulating and Releasing conditions – organisational context, decisions that might facilitate
5. Analysis of multi-affordance interaction –

6. Explanatory Power – Mechanism as strongest candidate explanation, "causal structure that best explains the events observed"

Adding to this understanding, Davis (2020) defines key mechanisms and conditions that cause certain affordances, which can be applied to any type and number of single or combined technologies.

Affordance mechanisms can:

Request or Demand, Encourage or Discourage, Refuse or Allow

And are influenced by Conditions (Context and Individual Capability) *influence affordances via:*

Perception, Dexterity, Cultural / Institutional Legitimacy

For example, the way that the design choices of a technological system afford certain actions, but the design does not absolutely limit other uses either. Design may allow or refuse certain actions, for example, a Touchscreen encourages more fluid, gesture interactions, but refuses direct 3D interaction, whereas, a keyboard allows quick typing of words but refuses gestures. This works at all scales, for example in an urban context, 'hostile'/anti-social design of a bench, e.g. adding studs, can discourage being slept on by homeless people.

Affordances are influenced by users' ability to understand the system, types of interaction, by level of experience, or skill. Therefore affordances are also related to cultural exposure/familiarity with a social-political context. Even where the technology potentially affords much, there may be a lack of understanding, due to e.g. due to life of technological deprivation, or a deeply engrained alternative experience (e.g. analogue vs digital childhood exposure) (Davis, 2020). .

As such, considering affordance as a key mechanism of design interaction, moves theoretical understanding towards more practical analysis of data gathered. The importance of a research methodology to be connected to research practice is increasingly acknowledged,

3 'STATE-OF-THE-ART' LITERATURE REVIEW

"Design takes place in the world of imagination, where one invents and manipulates ideas and concepts instead of the real thing" (Rittel, 1987)

This chapter presents a review of contemporary spatial computing (SC) research articles relevant to Co. Urban Design. The information ranges from prototype and influential ideas and applications to the current state-of-the-art, areas of emergent knowledge, and identified future potential. The first section introduces a fundamental aim, moving through key and emergent uses and further considerations. This leads to a research gap as a rationale for primary data collection that follows (6-7) and as a basis for discussion (8). An overview of the methods and scope of the secondary data used is provided in sub-chapter 4.3.

Spatial computing in various ways allows the immersive sharing of imagined ideas integrated into our spatial perceptive experience in ways that were not previously possible (Buhmann and VDE Verlag, no date). This enables users to directly review the significance of design ideas at scale and in a spatial context (Sørensen, 2006; Tomkins and Lange, 2019). Within this core functionality, research has increasingly begun to explore the capability of various areas of spatial computing and numerous potential applications that are relevant to Collaborative Urban Design processes.

Claims to Panacea.

In reviewing the academic literature on SC, there was found in many conclusions, a tendency to leap from singular studies, or technological verification towards slight overstatement of claims towards broad, universal benefits to collaboration, participation, or to the design process. For example: with statements like *"an AR democratization process"*, *"a new generation"* (Russo, 2021), *"between all stakeholders"* (Grassi and Klein, 2016), *"a game changer"*, *"benefits are proven"* (Matthys et al., 2021), *"revolutionized teaching"* (Wang, Ma and Wei, 2023), *"enhancing participatory planning"* (Maffei et al., 2016), *"without difficulty"* (Han et al., 2013).

Despite such glowing sentiment in conclusion, the situation was often presented in the wider research as more complex, especially when tested more widely, in a range of different contexts and with different participants. A caution towards overstatement was highlighted 25 years ago by Barndt (1998) when discussed the then emergent field of Geographical Information Systems: *"Advocates of GIS tend to talk as though this tools will revolutionize the community decision process"* but *"There is a danger that the opportunities will be* *oversold. The presumption that organisations only need new easy-to use software"*, which *"does not acknowledge the challenges to be met"*.

The following accounts from literature, consider this broader caution across the chapter's narrative, building towards a general critique of key benefits and drawbacks, questioning the absolute validity of such conclusions, and especially in the context where adoption is still low (Delgado, Oyedele, Beach, *et al.*, 2020).

3.1 Immersion, Presence and Validity

> *"…improves inclusive design communication and provides downstream benefits of better understanding, performance and problem identification, and commitment" (Griffith and Alpert, 2022)*

The primary affordance provided by spatial computing enables a sense of presence in the design space as a perceptually believable experience (Cipresso *et al.*, 2018). This has great potential to widen access by providing a visually native understanding of the spatial qualities that inform the design process and design communication (Seichter and Schnabel, 2005; Chowdhury and Schnabel, 2021; Matthys *et al.*, 2023). Compared to standard computer-based approaches, the immediacy of seeing and understanding the complex forms and spaces of proposals allows users to communicate with each other at scale and by positioning objects and arranging spaces in relation to their own spatial perception (Sørensen, 2006; Broschart, Zeile and Streich, 2013; Broschart and Zeile, 2015; Calixte and Leclercq, 2017). This adds capability beyond pre-existing (non-SC) systems, placing the user on the same 1:1 scale as the end user's experience (de Klerk *et al.*, 2019). This immersive experience, can enhance motivation, and through it's spatial, contextual nature, can give more clues to understanding a situation (Seichter and Schnabel, 2005; Saßmannshausen *et al.*, 2021),

Spatial computing methods have used digital 3D models for augmented views in the design studio (Ishii *et al.*, 2002; Seichter and Schnabel, 2005; Sørensen, 2006), for on-site 3D digital overlay on existing infrastructure, and for adding interactive manipulation abilities (Broschart, Zeile and Streich, 2013; Haynes and Lange, 2016; Piga and Petri, 2017). By displaying and situating the design process in this way, users' contextual understanding of design appropriateness can be increased via placement within a wealth of existing sites and differing cultural context information (Han *et al.*, 2013; Bustillo *et al.*, 2015; Chung, Han and Joun, 2015; Koukopoulos, Koukopoulos and Jung, 2017; Miskell, Salmond and Williams, 2017; Younes *et al.*, 2017). This immersive, experiential focus can elicit clearer memory retention than 2D displays, supporting longer-term, more sustainable decision-making (Van Leeuwen *et al.*, 2018).

Such direct spatial communication opens up ways to facilitate wider professional and public feedback into design, supporting and promoting a more collaborative process (Pierdicca *et al.*, 2016; Li *et al.*, 2018; Palmarini *et al.*, 2018), by 'translating', or bridging gaps between various professional and lay understandings (Broschart, Zeile and Streich, 2013; Matthys *et al.*, 2023). This also reopens ways to better incorporate non-verbal cues, such as body movements, gestures, and expressions, as a fuller spectrum of real-world human communication (Hong *et al.*, 2019). As such, it can help motivation and engagement (Koutsabasis *et al.*, 2012), bringing more efficient performance in design tasks (Fonseca Escudero *et al.*, 2017; Goudarznia, Pietsch and Krug, 2017; Jiang *et al.*, 2018; Kharvari and Kaiser, 2022). In combination, these capabilities can support greater long-term understanding and learning of the various layers and processes related to the urban design process (Fonseca *et al.*, 2014; Fonseca, Redondo and Villagrasa, 2015; Fonseca Escudero *et al.*, 2017; Kharvari and Kaiser, 2022; Darwish, Kamel and Assem, 2023) as a suite of tools to overcome long-established problems and gaps relating to understanding fundamental design principles (Wang, Ma and Wei, 2023).

> *Key developmental directions (for 'XR'): "easy to use tools, simulation of space and content, evaluation of results, continuous participation of stakeholders and adoption of XR solutions in architectural design, urban design and landscape architecture"* (Misius, 2021).

Ecological Validity

Relating to immersion and presence, is the notion of how valid the immersive experience is in comparison to real life (ecology). As such, this 'ecological validity' it has been shown that high resolution, high sensory, high context virtual environments can simulate real world applications, albeit with some limitations. For example, Litleskare *et al.*, (2022) found that participants 'walking' in their virtual forest, experienced emotional benefits that were similar to walking in a real forest. Similarly, Birenboim *et al.*, (2019) found with an urban city model, that immersion enabled users to pick up on more contextual cues and therefore choose more appropriate routes in ways similar to real life pedestrian activities, when compared to using still images.

Recent calls have been made to embed ecological validity considerations in virtual environment research. Joseph Browning and Jiang, and later Krukar & Schultz (2020; 2024) argue that visual, behavioural and contextual realism needs to be considered within architectural design work (including urban design, landscape, etc.). This is taken further by needs to consider including the following four dimensions as an assessment framework. Virtual simulation or overlays are compared to equivalent in the real-world, as:

- Visual Realism – quality and level of stimulus fidelity and sensory richness
- Behavioural Realism – as freedom to undertake certain movements and actions (i.e. affordances, see 2.4)
- Contextual Realism – level of cultural and semiotic references

From a User's Perspective

Communicating design using methods closer to real sight, movement, and experience within a 3d space can remove barriers, allowing non-experts to appreciate ideas more easily than prior abstract representation methods such as maps and plans (Simpson, 2001). Individual understanding of the design experience can be better understood from the individual's perspective view (immersive experience as an "ego spatial frame") as is particularly afforded by VR formats, seeing and reflecting on conceptual design ideas in a new way compared to traditional abstracted (allocentric) formats (for example, Plan, section) (Nisha, 2019).

In this manner, spatial computing can support user perceptions of the designed space. It can therefore be seen as a way of translating professional approaches, making them easier to understand (Broschart, Zeile and Streich, 2013), allowing quicker appreciation and intuitive use (Khan, Loke and Khan, 2017). For example, by adapting the perceived characteristics of virtual environment lighting and weather in VR. Felnhofer *et al.* (2015) demonstrated the impact on users' emotional reactions, which were akin to effects similar to those felt (seen and understood) in the real world. Thus, providing visual connections between knowledge of and understanding of the environmental context in which one is designing (Russo, 2021)

An Engaging Approach

Compared with professional software and systems which can be complex and confusing, spatial computing technologies have been shown to improve accessibility by being more intuitive, engaging, and creating more lucid memories of virtual experiences than non-spatial formats (St-Aubin *et al.*, 2010; Van Leeuwen *et al.*, 2018), particularly for laypersons (Fonseca Escudero *et al.*, 2017). Examining the incorporation of different AR technologies into five practices, Griffith and Alpert (2022) found that all increased participation, success, and engagement in the design process.

The nature of dealing simply with three-dimensional physical objects that are as perceptually familiar as to those of the real world facilitates interaction by a wider range of users (Broll, Lindt, Ohlenburg, Wittkämper, *et al.*, 2004; Alrashed *et al.*, 2015). This has allowed non-professionals to engage in ways that are playful, but with a strong impact on design processes (Broschart and Zeile, 2015). This occurs through a reduction in the disconnect between what they envisage and what they can see, thus allowing a greater focus on the expression and exploration of ideas (Chowdhury and Schnabel, 2020). Similarly, on users, information retrieval occurs even when related to complex datasets (e.g. if integrated with BIM systems) (Chu, Matthews and Love, 2018).

Cognition; Emotion, and Capacity (Load)

A person's perception and interaction with a place is not just a reaction to visual or physical stimuli, but is also influenced by memory of previous experience as an abstract expectation (Buhmann and VDE Verlag, no date). Therefore, the cognitive effects of immersion in virtual space are emotionally powerful. Using atmospheric environment design (different sky maps and lighting conditions), Moreau (2013) reported that they could elicit feelings of expected weather, such as being windy or humid, alongside comments such as 'it will rain'. In a similar exploration, Felnhofer et al. (2015) reported that they could induce certain emotional effects through manipulation of virtual environment design conditions (weather, lighting, and sound). For example, by creating deliberately undynamic conditions ("a boring environment"), participants experienced a depressed mood. The emotive nature of SC allows for research on design principles that were previously reliant on extensive and resource-intensive on-site studies.

These effects may be emotionally powerful and require careful consideration. The placement within, or of additional digital information into, our already complex perceptive and environmental experience needs to consider the level of additional 'cognitive load' on the user, as the extent to which users can process an increase in sensory information. If oversaturated, the performance of tasks can become more difficult, thereby reducing the ability to focus on relevant information. To reduce these effects, Raja and Calvo (2017) argued that systems need to be developed that are better able to blend with existing modes of spatial-environmental perception, rather than overlaying additional formats, such as signs and symbols which require further processing. This is in addition to the real surroundings (e.g. in an urban environment, walking across a road needs lots of reading of live events, cars, people, and weather conditions). In simple terms, the world as we experience it can be complex enough; therefore, we need to be careful of the level of overlay and integrate it carefully into the existing context.

From a cognitive perspective, evidence suggests that immersive design methods might produce better results but can be more taxing on the user. In a study by Umair et al., (2022) participants undertook and reflected on the use of VR, screen based and hand drawn production techniques to complete design tasks, and to review the extent of cognitive load, and specifically the extent to which tasks were 'mentally demanding, felt time pressured, or were 'frustrating'. They indicated that the load was highest in a VR environment, in-between when using screen based digital, and lowest with paper based. However, they also indicate that these differences also followed with better 'performance'. This is indicated as significantly lower time needed for production and for producing outputs which had less errors made. Similar conclusions were reported in a study by Wang and Dunston (2013), with an increase in speed and quality of work, but at the expense of worse user comfort of use (more encumbering, causing more fatigue or nausea).

However, the extent of cognitive capacity might vary based on context, with the ability to handle additional cognitive load being related to the various complexities of the wider overall task. For example, Ishii et al. (2002) reported that their novel spatial technology acted as a major distraction from the design task. Calixte and Leclercq (2017) also described a similar example where (even) the trained demonstrator displayed the effects of increased slowness and pauses of speech when presenting, a live interactive demo of their AR projection system. They suggested two interrelated reasons for this issue. The first was the cognition needed to navigate the differences between the display of design on the static model and the input device, a moving mobile tablet with a digital pen. The second related reason was the requirement for the user to ensure that what was displayed on the display was correct (accuracy and trust in the system). Lee et al. (2020), argue there is still much space for further testing as the impacts on mental and physical comfort for various types of SC systems need to be improved in order to facilitate wider adoption in practice.

Accessibility

The cost of SC technology is important to enable access by the general public (Portman, Natapov and Fisher-Gewirtzman, 2015), akin to that of smartphones, computers, and streaming services to ensure it becomes a staple technology, securing ongoing development (Cobrado Joibi *et al.*, 2019). Only 20 years ago, significant computing power and technological complexity made VR out of reach for government bodies (Portman, Natapov and Fisher-Gewirtzman, 2015, citing Pietsch 2000), and recent technological advances and commercialisation of SC systems via companies such as Meta (formerly Oculus), HTC, Samsung, and Google have brought down prices, making it accessible to bodies, universities, and design practices for low investment (Milovanovic and Moreau, 2017). Even with moderately expensive middle-ground systems, we might ask, would the costs actually be higher in total than those of making repeated physical models and printed plans? (Fonseca, Redondo and Villagrasa, 2015).

The increasing general commercial availability of SC systems and relatively low costs, as well as the technological relationship to smartphones, are facilitating widespread use. This scale of access creates increasingly viable development costs that support wider use cases (Milovanovic and Moreau, 2017; Cobrado Joibi *et al.*, 2019). And, for example, the current use of smartphones can be an intermediate, cheaper option for testing/development of applications that might later be used with more sophisticated (currently much more expensive) head-mounted systems (Anagnostou and Vlamos, 2011). For example, in future iterations to integrate inertia measurement systems to assess participant movement in more detail (Çöltekin *et al.*, 2020), or eye tracking to assess level and areas of interest via users' visual preferences (Frutos-Pascual and Garcia-Zapirain, 2015; Simpson *et al.*, 2019). Aligned to this, online connection, as needed for VR systems for public participation, is generally of reasonable quality relative to low prices for development (Jiang *et al.*, 2018).

Removing Barriers

Spatial computing can close the gaps between design experts who have training in abstract representation and non-experts, who benefit greatly from having detailed information presented so literally (Chowdhury and Schnabel, 2020). This is useful for better understanding the spatial qualities of design, which are positioned within the surrounding context of those design ideas (design ideas placed in the real world) (Tomkins and Lange, 2019). This has been found to support the interpretation of design data by varying groups of collaborators, who may have different backgrounds, perspectives, and experiences (Wang *et al.*, 2014; Bilge, Hehl-Lange and Lange, 2016; Kamel Boulos *et al.*, 2017; Chu, Matthews and Love, 2018).

This can improve performance as quality and speed of work are produced, including capability and spatial skills (Fonseca *et al.*, 2014), although there may be reluctance to develop new knowledge in these areas. This might be because the use of technologies that are new to the user might be felt to get in the way of the flow of the design process due to encouraging a focus on the technology rather than the design (Ishii *et al.*, 2002). This might be improved by combining the visual capabilities of SC with increasingly capable tangible abilities at the user interface (Broll, Lindt, Ohlenburg, Wittkämper, *et al.*, 2004), for example, better, different types of controllers, hand tracking, and haptic feedback.

Where attendance in person becomes a barrier, SC implementation has demonstrated the viability of on-site and remote collaborative environments, where participants can view and discuss design ideas presented in a virtual or mixed SC-real space (Tomkins and Lange, 2019). For example, the combination of high audio-visual quality with online remote access is now relatively inexpensive (Jiang *et al.*, 2018) and opens up new ways to allow co-presence and co-actions in the virtual space (including long-distance remote access), providing a sense of togetherness in the design process (Hong *et al.*, 2019).

3.2 Design Processes

Intuitive, Efficient, Collaborative; but currently Limited

As stated, a key benefit of spatial computing is that it provides an intuitive user interface that can extend spatial communications beyond specific conditions presented by physical constraints, such as location or time (Anagnostou and Vlamos, 2011). SC's visual immediacy can improve the efficiency of the collaborative design process (Alrashed *et al.*, 2015) by supporting simultaneous user interactions in collaborative engagements (Ishii *et al.*, 2002). Tangible integration of digital objects into a real space (AR/MR), with real time interactions of scale and location present collaborative environments that require "no prior training" (Fonseca Escudero *et al.*, 2017), reducing the complexity of understanding and removing the need to 'take turns' to individually create design additions (Broll, Lindt, Ohlenburg, Wittkamper, *et al.*, 2004).

It has been shown that the use of gesturing and sketching in VR improves the speed of early conceptual modelling tasks (de Klerk *et al.*, 2019). Similarly, using AR to view Building Information Management (BIM) software allowed significant increases in speed (+50%) and accuracy of information retrieval (Chu, Matthews and Love, 2018). The speed and efficiency benefit from the ability of SC systems, allowing users to represent and consistently place the design in context and focus on the design object/space/task (Wang *et al.*, 2019). A study by Wang and Dunston (2013) found that although the use of a new system (tangible MR) required an initial additional time to learn and use, in the longer term, the immersive capability facilitated greater understanding, which led to overall faster production, while also improving problem solving, error checking, and slight improvements to output quality. However, they argued that the key benefit provided is participant satisfaction in a more collaborative process.

One suggested reason for this is that immersion affords real-time comparative design verification (Fonseca *et al.*, 2014). These kinds of interactions can improve collaborative design actions, such as the positioning of objects, where multiple users can place, objects in space and view from different angles and then move accordingly alongside discussion, and instantly checking with others within a quick feedback loop process (Fonseca Escudero *et al.*, 2017). Users' ability to position objects within/on a 3D model freehand becomes more accurate, more like in real life (Chen and Huang, 2013; Fares, Taha and EL Sayad, 2018).

Technical Limits

Despite several general collaborative capabilities, technological limits still exist. The integration of all features and functions simultaneously is taxing on the hardware. As with any computing type, compromises need to be made between greater portability and greater power. Wang et al. (2019) defined two common compromises of AR/MR that influence broad co-design functionality:

1. Visualisation only and no interactions - deliberately limited, but lightweight, for activities: seeing - inspection, basic annotation, potentially higher resolution/rendering capability.
2. Simultaneous design – affords more advanced interactions, for multiple collaborative interactions, co-modelling, often at expense of more limited geometry/rendering resolution.

Moving forward, it is important that the design and development of SC software to Co.UD, needs to be driven by teams who understand the requirements for co-urban design, as "good, useful, and thoughtful experiences that can only be achieved with interdisciplinary collaboration' (Çöltekin et al., 2020). Similarly, the software needs to align design with site conditions. For VR, this leads to a requirement for extensive world building, or scanning of the environment, which often presents difficulty in reproducing the full dynamic and diversity of senses of a site context virtually. For AR/MR the mixing of digital objects into the real allows such an in situ design (Gill and Lange, 2015). The ability to design ideas tests through multi-perspective to appreciate the size, scale, and position of 3d objects within the spatial context to which the design is intended (Grassi and Klein, 2016).

More broadly, significant challenges remain as a communicative interface. Billger, Thuvander, and Wästberg (2016) highlighted five key challenges related to "Integrating and representing data; avoiding misinterpretation; managing visualization tools; and development of engaging dialogue processes". In terms of encouraging wider social interactions, a highly immersive SC might be less favourable. Khan, Loke and Khan, (2017) found that the individual focus of VR systems, being visually and therefore socially all encompassing, reduces users interacting their surroundings and other people. In this study, Milovanovic and Moreau, (2017) specifically chose an immersive CAVE system, over head-mounted VR, to "conserve natural communication behaviour. Whilst AR/MR allow integration with the real world context, there are currently a number of technical limitations such as low field of view, low graphical capability, visual 'clipping' which mean that in many cases a monitor/projector has advantage of being stable and an inherently shared view (Moloney et al., 2020).

Collaborative Virtual Environments (VEs)

Design actions which are easier and closer to real-world mechanics were enabled by ability for users to move about in the space whilst discussing spatial features and interacting with 3D models. This facilitates and engages integrates co-design processes, rather than more concurrent, but individualised actions (Ishii et al., 2002; Broll, Lindt, Ohlenburg, Wittkämper, et al., 2004). Virtual environments that are large format, immersive, and multi-user can increase the type and range of engagement, with increased verbal communication and body language, compared to single-user interaction (laptop or monitors) (Ishii et al., 2002). Non-verbal cues, such as body movements and hand gestures, have been shown to increase the feeling of proximity and bonding (Hong et al., 2019). Scaling from the virtual design studio to the virtual or mixed reality public space allows connection to daily activities in the real place. Aligned to personal device connection and social media, such virtual places can blend with real context in questions to be used to promote more active, local civic discussion between stakeholders (UN Habitat, 2019).

At the same time, there can be gaps between these virtual ideal scenarios and the realities of digital delivery, especially within the complex conditions of public engagement. Ideas of hosting a politically neutral digital space for public-professional debate may turn out to be idealistic. When tested in real-world conditions, issues such as poor engagement and highly variable expectations can present themselves, creating an even less certain situation when they are removed from the physical context (Rizzo and Galanakis, 2017). Within these cautions, there is still benefit in creating spaces where people can effectively co-design, as they can allow greater efficiency through the ability to instantly see each other's design ideas come into fruition, giving opportunity for 'real-time feedback'. This can help public users feel more engaged and more accepting, through greater access to the collaborative processes that informed decision making, as a better shared understanding (Alrashed et al., 2015). Such interactive, 'immersive co-presence' allows "immediate action/perception coupling", which can increase cooperative, rather than competing actions (Calixte and Leclercq, 2017). This "what you see is what I see", creates more collaborative actions, completed more quickly (Gül, Uzun and Halıcı, 2017), so that participants act as "design units", following a shared "perceptual awareness" of 3D design ideas, even when working remotely (Chowdhury and Hanegraaf, 2022).

The ability to join a virtual design studio or public co-design space can open access for those not able to attend in person to still interact in ways that feel directly related to the 3D environment of the design project context (Seichter and Schnabel, 2005; Seichter, 2007b; Batty and Hudson-Smith, 2014). In this remote situation, users may need to discuss their organisational process in more depth, so as to coordinate the more separated roles and tasks (Gül, Uzun and Halıcı, 2017). The design conditions of the multi-user environment and technical capability of the technology and the specific action/activity have an impact on the type of collaborative communication. For example, a study by Gül, Uzun, and Halıcı (2017) found that users spoke more when sketching than when working in 3D, irrespective of the technological mode: analogue, digital, or (digital-) spatial.

Design of Collaborative Virtual Environments

The broad aim for collaborative virtual environments, is for efficient capability which is context located, empowering diverse, multi-user function within an interface that is easy to use as well as collectively fun, and allows exploration (Olsson *et al.*, 2009). It is important that SC software becomes much more accessible, allowing editing of content in app ('3D') as well as to more effectively facilitate collaborative communication between participants (Reinwald *et al.*, 2014).

For any digital technology, it is important that users focus on using the system rather than dealing with technical issues (Bradecky, 2021). Aligned to this, Orland, Budthimedhee and Uusitalo; and Orland (2001; 2015) suggest key principles for collaborative VE design, the 5 'I's:

- Illustrative, with clarity
- Immersive - user feels like they are in the space
- Interactive - has an interface that allows manipulation
- Intuitive - following ergonomic design of interface
- Intensive – a deep, engaging experience

Similarly, the requirements for Collaborative Virtual Environments (CVE/VE), is summarised by (Gül et al., 2013) – presenting a framework of principles to enable/enhance successful collaboration:

1. Process Tasks
    a. Planning – enable engaging understanding and description of VE as space and object
    b. Creativity and Brainstorming – have environment/models which allow a quick process of idea to creation
    c. Decision making – allow participants to be in visual-spatial sync, see real time changes, for effective design review
    d. Cognitive Conflict – allow multiple and varying interactions, as intuitive design actions and communications
    e. Competitive Performance – facilitate equality of team member participation, via responding to individual cognition with user specific visual feedback to enable greater sense of presence
    f. Information Dissemination – incorporate communication tools in a shared work environment, allowing exchange of ideas, including from wider data sets
2. Collaborative Processes
    a. Social Protocols – facilitate in the communication and organisation of roles, and relationships, including at the micro interaction level, social expressions – e.g. use of detailed Avatars
    b. Group Characteristics – adaptable design, allowing fluid shifts of user modes and team arrangement styles, including from individual to co-creation tasks related to different stages of process

Aligned to Design Processes

Overall, the shared environment is important for integrating creation and ideation processes through co-design. Individual computers (non-SC) often require a back and forth shifting between processes, such as hand sketching, to digital 3D modelling, which can slow down, separate, and detract from design ideas. By designing more integrated solutions, which combine digital and physical modelling via SC, we can realign these processes (Gül, Uzun and Halıcı, 2017). Part of this integration is the need for social engagement and peer support systems, as important for facilitating successful collaborative working (Šašinka et al., 2019). Alongside this, it is preferable for users to be able to control their own navigation, allowing individual observation for design review increased level communication and understanding (Koutsabasis et al., 2012).

Similarly, it is important to enhance non-verbal communication via body language, such as through: "face, tilts of the head, body posture, and skeletal muscle movements", elements often masked when in virtual environments. Though, even where there are avatars, they can lack the absolute nuance of real, 'face-to-face' encounters, and important emotional details such as if someone is "paying attention, agreeing, or attempting to respond" (Šašinka et al., 2019). In their study, Šašinka et al. (2019) found that when using VR, these affordances were missing, but participants created ways to recreate some of the most important body language communications. They also still followed social rules such as adhering to each other's personal space.

As SC brings the benefits of digital content to our spatial realm, it is still unable to create physical interactions with real objects. It may be that real-virtual interactions in mixed reality are needed which can maintain a focus on the tactile 3D experience as a primary goal (Gordon and Manosevitch, 2011). These mechanical functions are arguably important (Vosinakis *et al.*, 2008). One well-tested example is the Tangible User Interfaces (TUIs), which enable interactions between digital and tangible (real, physical) elements and which have been found to be highly engaging (Chen and Schnabel, 2009; Wang and Dunston, 2013; Alrashed *et al.*, 2015; Alonso *et al.*, 2018). Such systems may form a useful transition to increasingly tangible digital overlays (via haptic feedback) or may prove to be the most effective way to provide a seamless blend between real and virtual objects and spaces. In any case, there is a strong need for open reflection on which areas can provide the best improvement and reproduction for successful design processes.

Analysis of Physical & Cultural Place

Digital immersion offers ways to better understand space and context by bringing together real and digital contextual information (Moural and Øritsland, 2019; Saßmannshausen et al., 2021). SC overlay can intuitively reveal previously hidden or separated datasets (Olbrich et al., 2013). It presents 3d space to users as is, which moves away from the visual distortion present when viewing places via 2D formats (Kim and Kim, 2019). For replication of real information as a virtual copy of real life places, 'Digital twins' can facilitate the study of various attributes of a place as spatially located data, accessible as a 3D model (UN Habitat, 2019). This can be a rich contextual basis for design work (Chen and Huang, 2013). For example, it has been shown that by switching between various simulations, that people are better able to recall landmarks and navigate themselves in places that that were physically dynamic/diverse (Shushan, Portugali and Blumenfeld-Lieberthal, 2016).

Physical data

There are now many options for simply converting physical design artefacts into digital 3D models and data sets. For example photogrammetry software, using a series of 360 photos (Portalés, Lerma and Navarro, 2010; Lescop and Chamel, 2020), or 3D digital scanning (Song et al., 2009) allow automated conversion of real objects into 3D models. This greatly reduces the time needed to manually build the 3D geometry and adds potential for much quicker user input of contextual site/design data (Ioannidi, Gavalas and Kasapakis, 2017), as much for for virtual environments, as creation of augmented elements. Similarly, physical models of whole urban landscapes can be gained quickly using Unmanned Aerial Vehicles (UAVs/drones), creating a highly accurate, photorealistic digital twin of site contexts. They can also include other layers which would not be seen by the human eye by using various scanning technologies, such as thermal or alternative light spectrum sensors (Stanga, Banfi and Roascio, 2023).

Experimental platforms, such as MIT CityScope (Alonso *et al.*, 2018) and Tangible Interface at KACST (Rose et al., 2015) where multi-user collaborations can explore changes that interact with contextual data (Krietemeyer, 2017), such as changing road, or building layouts affecting traffic or wind simulation in real time.

FIGURE 17 - MIT 'CITYSCOPE' 2021

Immersion in a data-rich 3D spatial environment can facilitate individuals' experiential perspective (egocentric) sense of place (Nisha, 2019) via remote virtual simulated view (Salter et al., 2009) or overlaying digital elements onto user views on-site (Fonseca et al., 2014). In these ways, SC can be used to simulate and test theory on contextual understanding. For example, immersive experiences have been used to show people's varying ability to read the urban landscape, by testing how well they remember routes, scenery, and especially the structural arrangement of landmarks (Bruns and Chamberlain, 2019). Similarly, immersion can be used to test the perception of spatial principles. A study by Kim and Kim (2019), for example, found that users' optimal civic space dimensions (ratio of depth to height) differed from those claimed to be optimal in urban design theory. A similar study using VR with visual and audio stimuli by Liu and Kang (2018) indicated that people's feelings of comfort in a space could be directly influenced by changes in these spatial ratios. Within these explorations and aims, there is much scope for further study, with a wider range of sensory elements considered that work at different scales of data, from large planning/urban design, down to architectural scales (Portman, Natapov and Fisher-Gewirtzman, 2015).

Social data

SC can be used not only to support users' navigation of physical place, but also to present aligned information, as well as to encourage users to submit their thoughts and design indications, which is a source of crowdsourced perceptual data (Ioannidi, Gavalas and Kasapakis, 2017). Similarly, information can be sourced on future aims, or aspects that no longer exist but are still held as valuable. Thus, developing richer information on historic settings. For example, the digital reconstruction of a castle (now in ruins) as a civic resource (Matthys et al., 2021) or capturing social histories, including forgotten or under-represented (Oleksy and Wnuk, 2016), This kind of information can be effectively crowdsourced, support digital twin models, and digital informational overlay. Similarly, integration with building information modelling (BIM) can facilitate the contextualisation and navigation of datasets in-situ/on-site and needs to develop interaction between existing and new data from site conditions (to be 'context aware') (Wang et al., 2013).

The use of mobile technologies particularly supports the flow of multilayered public data, including elements which provide critique and feedback of urban place functions (Zheng, 2019). Though not without ongoing discussion over privacy concerns, the incorporation of this 'big data', such as peoples movement around urban places, via is already being used to improve various governmental services (Tunçer, 2020), such as waste management, public transport, security and safety, etc. (Krietemeyer, 2017). Such connections between social media and planning systems enable new ways for the public to provide feedback (Gill and Lange, 2015),.

Tunçer (2020) argues that we need to move to processes where design requirements inform which data gathering is needed, rather than data being collected in only ad-hoc ways which may or may not be useful for design purposes. In this way, we would be able to incorporate many more useful layers of information from different sources and scales to deeply inform design decisions. Taking this further, we might explore AR (and VR conceptually) as a 'transparent' mode and interface for collating and communicating data. For example, facilitating a better understanding of user happiness and function within certain environments and evidencing wellbeing walkability studies by highlighting preferences for natural settings and recreational destinations (Tunçer, 2020).

3.3 Future Aims and Potential, Current Limitations and Improvements

Twenty years ago, Broll et al. (2004) suggested that AR was 'still' not ready to replace desktop computing for architectural design. Although significant advances have been made since, these have only further highlighted specific gaps in capability, both in terms of quality and scope. The technologies still suffer various technical limits, such as "form factor, see-through quality, the field of view, image quality, handling occlusion, vision correction capabilities, etc. '(Delgado, Oyedele, Beach, *et al.*, 2020). Furthermore, there is a lack of best practices and options for types of approaches for software applications (Saßmannshausen *et al.*, 2021). At the same time, it is important to consider that with developing technologies it is easy to focus on the various limitations, but every development does bring increased benefits (Broschart and Zeile, 2015).

> *The A14 chip of the 2020 iPhone: "If released in 2009…would have made it the top 500 supercomputer in the world! It has more computing power than the most powerful computer in the world in 2002" (Truong, 2021)*

Technical Capability: Power, Speed, Quality

There have been ongoing calls for a number of key improvements to technical capability, such as for increased handling of larger files and 3D objects scene, that is, more complex, better quality (Fonseca Escudero *et al.*, 2017), zooming into increased details, better lighting /shadows, tracking accuracy, and quicker-smoother synchronisation (Wang and Dunston, 2013). However, there is a need to recognise the inherent limitations of more accessible (mobile) devices on the size and complexity of models (Gill and Lange, 2015), which are harder to handle (Wang, 2009). Therefore, for the more accessible SC forms, mobile VR, and generally even more so for AR, the level of graphical quality is significantly lower when compared to the very best that can be achieved with traditional computers (i.e. with much lower processing power, lack of dedicated graphics).

The rendering of believable virtual environments (for VR) is particularly taxing on computers, where additional graphics resources are needed as the environment detail is increased (geometry and materials). Mobile solutions are often limited to lower fidelity of visual form and, in some cases, less consistent physics behaviours (Koutsabasis *et al.*, 2012). Such lower technical qualities and calibration can result in, for example, a lack of visual clarity, lower detail, depth (perception), and field of view, which can then cause more user fatigue, especially those less experienced (Nisha, 2019).

In addition to these major compromises, all types of SC also need to process additional information beyond the basic rendering of a model. AR/MR need to analyse the real world via cameras, VR requires rendering of two scenes, to simulate 3D depth, separate rendering for each eye (double processing requirement). Alongside this sit limitations posed by the requirements to be comfortable and mobile (i.e. lightweight, battery powered). Advances in cloud-based graphical rendering services have the potential to remove the need for advanced processing power on local devices, for example, head-mounted AR devices or mobile phones (Shi and Hsu, 2015), although offboarding to external services then shifts the requirement for advanced networking bandwidth/processing, which may be especially limited in live contexts (using mobile data).

Chi, Kang and Wang, (2013) argued for 'context aware AR', that will be possible through improvement to quality of tracking, through a combination of more detailed scans of local environment combined with GPS satellite data, to allow precise and stable placement of objects in a scene, especially useful outdoors which is often the most difficult (due to variable conditions). There has been a general shift more recently towards these aims, moving from marker-based tracking, to marker-less, via the increasing capability of mobile hardware (smartphones and smartphone tech for headsets), thus allowing more detailed, quicker mapping of the environment, facilitating more complex, multi-objects placement: people, vegetation, etc. (Goudarznia, Pietsch and Krug, 2017) For example, in ability for increased placement distance from camera, or size of view (AR on mobile, field of view), to better see details of design features (Fonseca Escudero *et al.*, 2017).

However, minor issues remain that can impact users' perception of space, especially when using AR to experience undesirable visual glitching, including loss of tracking (Wang and Dunston, 2013). Such tracking issues have been shown to restrict mobility and reliability of use, giving limits to understanding of specific environmental conditions (appreciating correct surfaces, patterns, etc.) (Wang, 2009). The perceptive smoothness of tracking is influenced by the lag (time latency) between visual feed and changes in position and movement (Buhmann and VDE Verlag, no date). These effects can cause reduced feelings of control, which can result in user frustration, as users are not certain which objects are fixed and which may be editable (Alrashed *et al.*, 2015) as an affordance mechanism (Davis, 2020). Keeping objects in position using AR relies heavily on the ability of hardware and software to lock digital objects relative to the processing position in 3d space (Chi, Kang and Wang, 2013).

Increasing camera and processing performance allows better rendering and improves users' capability to understand spatial depth (Wang and Dunston, 2013), which has seen exponential improvements. However, many devices lack accuracy and precision of location (Ioannidi, Gavalas and Kasapakis, 2017). On site, there are often more complex visual conditions. The challenge for digital processing is made more challenging in these conditions, where more complex terrain and surface materials and/or changeable real-world lighting can have an impact, especially outdoors. This can influence the ability of camera processing to keep hold of the marker environment, reducing the precision and retention of digital elements (Ioannidi, Gavalas and Kasapakis, 2017). They also need quicker processing, more responsive movements, and interactions. As capabilities increase, expectations also increase. Technical developments allow multiple reference points for the same point to increase accuracy (Fonseca Escudero *et al.*, 2017), which is important for stability and reduced visual glitching, especially as the complexity of models increases (Fonseca *et al.*, 2014).

Range of software and inter-compatibility

Currently there are a range of emergent, or rapidly developing hardware and software options within spatial computing. This makes it unclear what types to select for a given project (Gill and Lange, 2015). This situation also relates to the software used to make, edit, share content that feeds into SC. The software of architectural design, gaming, and animation modelling for example, all tend to have different standards, of which SC is often more closely situated to the latter. These differences in formats can make the transition between software difficult (Fonseca *et al.*, 2014). This requires adaptability to different scenarios and use cases.

Realism

The continual development of wider computing technology has been pushing towards higher quality. In recent times, this has become so sophisticated that rendering levels might soon be able to match those of real objects and environments. For example, with correct light and shadow, to blend with that of the surrounding physical environment (Fonseca Escudero *et al.*, 2017). Indeed, a current issue with mobile capabilities, particularly AR, but also mobile VR, is that a lack of detail/quality of virtual environment. This can influence the ability of participants to orient themselves (Chowdhury and Hanegraaf, 2022). There are considerations that will need to be made about the level of realism that is most appropriate for design. Somewhere between extremes may be most appropriate for UD, as a 'semi-realistic' visualisation, which avoids the sense of unease that can come very close to reality (Moloney *et al.*, 2020). These considerations also relate to notions of 'draft' work, that is indicative, for design review and feedback. This would not only avoid the time and resources needed for creating high end design visuals, but may be better for presenting design ideas which are not yet set in stone (Meeda, Parkyn and Walton, 2007).

Networked, Data supported

Facilitating various applications for collaborative SC, such as onsite AR or multi-user VR, requires a robust network setup. Cloud-based, quick connections with high bandwidth and low latency are highly desirable to enable quick visual communication in external, on-site conditions (Russo, 2021). This would open new options for design and site analysis, quickly relating data to location (Gill and Lange, 2015). However, typical networking speeds for connecting SC devices to other digital systems and databases are not yet adequate to avoid all problems. This can impact user experience, such as increased motion sickness from out-of-sync visuals, due to networked data latency (Torres Vega et al., 2020). Three key improvements, are suggested

1. Not only improved transfer and networking speeds, but also more efficient systems for reducing the level of data transfer requirements.
2. Systems need to be able to adapt to contextual networking information to optimise between different setups and systems.
3. Able to efficiently capture data and evaluate system performance.

(Torres Vega et al., 2020)

Intuitive, shared User Interface Design and User Experience (UI/UX)

As UI design can cause confusion, leading to frustration, it is important that systems can provide a user experience (UX) that presents clear instructions and facilitates comfort and visual understanding of what is happening in view (Alrashed et al., 2015). This includes the need to improve control mechanisms, that is, moving away from screen tapping (tablet/iPad) through natural bodily movements, for example, via tracking of specific hand, head, eye, and body movements with increasing accuracy. Ideally, this can be achieved without the user needing to wear anything in addition, and be combined with high resolution and high field-of-view capabilities (Raskar, Welch and Fuchs, 1998). Similarly, current gaming or tech orientated interfaces can often feel overly complex, or gimmicky. These factors focus users on a need to learn the hardware/software system, rather than facilitating their focus on expressive design (Nisha, 2019). Aligned to this, differences have been shown when judging distances (in AR), indicating that even small differences between real and virtual can similarly cause a perceptive misalignment (Pointon *et al.*, 2018).

TABLE 4 - IMPROVEMENTS NEEDED FOR AR IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION (AEC) SECTOR

Type	Requirement
Engineering-grade AR and VR devices:	Comfort and safety approved
	High accuracy tracking
	Improved indoor localisation systems
	Dynamic 3D mapping of changing environments
	Explicit indication of accuracy
	Larger model capacity
	Longer battery life
Workflow and data management:	Archiving AR and VR content and experiences
	Visualising data in a 3D spatial and temporal context
	Developing data exchange standards
	System integration with other built environment systems
	Multi-user and multi-device capabilities
	Addressing security, privacy and data ownership issues
	Develop an upskilling roadmap
New capabilities	Real-time model modification
	Diminished reality and real-time occlusion
	Automatic environment capture
	Real-time integration with internet of things (IoT) devices
	Multimodal human–computer interaction (HCI)
	AR and VR teleoperation and plant control

– SUMMARISED (DELGADO ET AL., 2020)

Considerations for SC as presented in the literature

- Variable combination of interest and uncertainty, owing to the uncertainty of experience, new VR users display a resulting in limited movement and lack of talking. With experience, these effects decrease with increased movement, both physically and in the virtual space (Moural and Øritsland, 2019).
- Limited time desirable inside the headset due to lack of comfort: weight, and/or motion sickness, and especially if the user is wearing glasses. Movement can be restricted if tethered by a cable. (Nisha, 2019).
- Capability relies on developments in the entertainment industry, due to the much larger market (Orland, Budthimedhee and Uusitalo, 2001)
- AR lacks best practice examples for design, including a lack of equivalents for established methods, such as Lego, clay, and other craft modelling materials (very established methods for participatory planning) (Saßmannshausen *et al.*, 2021).
- Experiences are not real but are representations of the real (Simpson, 2001). The approaches that we use to communicate design, such as scaled models and perspectives, Different representational formats are used to communicate design ideas.
- Representations not always consistent, different presentations of the same space or object by different users. This is influenced by level of prior experience with SC (Milovanovic and Moreau, 2017).
- Some argue that AR and VR are additional methods that are best suited to supporting traditional methods as compliments CAD, filling a gap relating directly to the understanding of scale (Broschart, Zeile and Streich, 2013; de Klerk *et al.*, 2019).
- Lack of consistent collaborative formats, or environments (platform)
    - Real sketching is by default a shared environment; one paper can be drawn on by multiple people, can require advanced skill
    - 2D map/section drawings are standard, but can be hard for the public to understand
    - 3D models are take longer, therefore used after decisions have been made (Matthys et al., 2023). Tends to require separate processes either focusing on independent quality processes or reliant on quality of collaborative modelling environment (Gül, Uzun and Halıcı, 2017).

Interaction with the Real World

As the quality of virtual elements increases, the difference between reality and high quality, 'photorealistic' visualisations may become hard to discern (Lange, 2001; Broll, Lindt, Ohlenburg, Wittkämper, et al., 2004). Increasingly, the digital elements overlaid onto our physical world may be cognitively indecipherable, blurring the perceptive boundary between reality and fictional elements and spaces (Walz, Gloor and Bebi, 2008). However, with increasing device power (even mobile), there is a shift from sole focus on resolution towards interactions (Cipresso *et al.*, 2018).

> *"Location-based augmented reality game 'Pokémon Go' resulted in large, concentrated numbers of visitors". "recorded 6.3 million visitors", "an increase of 12.5% compared with the previous year" (Government of Western Australia Botanic Gardens and Parks Authority, 2016).*

The AR game 'Pokémon Go' highlighted the potential for SC to greatly increase engagement with real places (Kamel Boulos et al., 2017; Kozlowski, 2017; Potts, Jacka and Yee, 2017). Despite this spatial/physical blurring, there was a legal policy disconnect resulting in a list of real issues caused by the unplanned increase, such as overstaying beyond opening hours, traffic congestion, nuisance noise, additional refuse collection and police presence. This lead to requests from the authority to the game developer for a physical event permit (Kozlowski, 2017).

> *"a real experience implies a realistic interaction and not just great resolution. Interactions can be improved in infinite ways" (Cipresso* et al.*, 2018)*

At the extreme extent of potential influence, we connect to what Baudrillard defined as "hyperreality", where entirely fake realities subvert our appreciation of reality, with potential for loss of knowing the original reality (Wolny, 2017). For example, Disneyland can be understood as a fake reality from imagined entertainment. VR presents ways to extend the possibilities, as well as the deep considerations this might present to the urban realm.

FIGURE 18 - "CITY SATURATED IN MEDIA" AS CONCEPTUAL VIDEO 'HYPER-REALITY' (MATSUDA, 2016)

Concluding: aims for SC-CoUD

For co-design, we might look for abilities that are entirely accessible, fulfil a vast range of functions, meet the requirements of different professionals and stakeholders, and are reliably smooth outside of lab conditions. Digital technology for collaboration has increased with huge advancements in capability and the level of available data, but has gaps as a communicative interface, including organisational management in terms of ownership, maintenance and training (Billger, Thuvander and Wästberg, 2016).

Though not without strengths and benefits, no solutions provide a 'catch-all', but rather, add their own capabilities, with specific issues and considerations associated (Brown *et al.*, 2017). Any downsides, or limits need to be placed into a wider frame of analysis, as no digital technologies in any form are 'perfect', let alone emergent ones.

The emergent nature of digital technologies for use in co-design is similarly complex and uncertain to that of the urban context itself (Brown *et al.*, 2017). Technological innovation has limits to what it can achieve, and changes need to be echoed in organisational and social system improvements (Parjanen, 2012). To avoid the often-disconnected approaches currently used, it will be beneficial to produce systems that are flexible enough to obtain information on processes and backgrounds, irrespective of user type (Tinati *et al.*, 2014). For visual communication, there are key considerations in representing and integrating data, understanding it by users, system management, and creating an engaging interface (Billger, Thuvander and Wästberg, 2016).

Need to test further

> *the shift to consumer SC equipment and the context of "societal challenges, e.g, sustainable urban development, big data…", "signals an opportunity to overcome the barriers"…to "focus on the innovation benefits of this digital transformation" (Griffith and Alpert, 2022).*

Reviewing the literature on AR/VR, the majority indicate positive benefits and evidence with their results. An example outlier in this context raises some important perspectives; Tai (2023) tested teaching of in-situ hand-drawn sketching of place using five methods, from in-person demonstration, through various illustrative and digital means. In their study, students indicated the highest preference for in-person guidance and the lowest preference for AR/VR (immersive videos). Although the methods and devices used had specific limitations, their study highlights some inherent weaknesses of spatial computing that seem less acknowledged and need to be tested further. Most pertinent of these, the clunky hardware, which is not suited to outdoors, or socially complex situations, and which does not have the absolute fluidity, and interactivity of live-in-person interactions (such as drawing). Those points related to more established types of SC. Problems may be expanded for more emergent areas of SC.

3.4 Gaps presented in Research Literature

> *"Although these technological tools are useful mediating devices, they are not a panacea to the challenges of interdisciplinary collaboration or public engagement. Indeed, they produce their own particular challenges"* (Brown et al., 2017)

Despite great promise, there are still many uncertainties around the use, trajectory, and integration of spatial computing. Even where potential is widely recognised across areas of built-environment practice, the actual use cases perceived is still very low (<5% of projects) (Delgado, Oyedele, Demian, *et al.*, 2020).

As general visualisation tools have become commercialised and more accessible, there has been a shift in research focus from specific technical development, such as experiments and prototypes, towards focus on testing through application in real-world contexts and processes (Billger, Thuvander and Wästberg, 2016). There is an affiliated trend and need for extended reality (XR: spectrum of augmented to virtual reality) to connect to various wider areas of computing to see true benefit: hence, 'spatial computing' [see - 2.2]. The majority of studies have looked at developing or testing new applications, rather than looking at adoption or open, diverse user evaluations (Stals and Caldas, 2022). This seems particularly important when trying to understand the multiple discipline subjects of Urban Design. There is a need to move beyond a technical focus, to understand the problem/opportunities presented as a whole, via an integration of the technological, design, and human factors (Çöltekin *et al.*, 2020).

> *"Technological fidelity should not be a surrogate for conceptual rigor - it could instead usher in the exploration of deeper underlying causes and alternatives." (Khan, Loke and Khan, 2017)*

In this vein, this research looks towards aims for integration and is intended with the use of the term 'spatial computing, as an amalgam of AR and VR to computing – all, any. This also intends to shift the focus of enquiry from how do we do this? To include ways to better understand how we should do this? with questions of why or why not?

The following sub-chapter collates and summarises the relationships between key gaps in Strategic, Narrow and Specific knowledge that influence our understanding of SC systems for Co-design in Urban Design, presented and analysed from related research literature.

1. Strategic – Urban Design, Co-design: theoretical, broad influence, testing in new contexts
2. Narrow – Digital Tools for Urban Design, Co-design – key aims and objectives, increasing nuance, development
3. Specific – spatial computing (SC) for Urban Design, Co-design – specific affordances, emergent applications

Adapted from (Chi, Kang and Wang, 2013)

Theoretical and Strategic gaps

Despite significant technological and conceptual developments over the last two decades, spatial computing still defines an emergent landscape of interrelated technological exploration. Within this broad spectrum, there are many areas to explore further and in more detail (Portman, Natapov and Fisher-Gewirtzman, 2015). Aligning spatial computing to urban design is an additionally complex challenge due to the multilayered changeable nature of urban contexts, and because urban design is not an agreed, static discipline in methods or direction, for example, as represented in the arguments of Marshall (2012), towards clearer definition and more validating evidence (see Chapter 2.1). Such uncertain variability and complexity demand transdisciplinary thinking, but there have been limited SC related studies which 'truly' combine discipline agendas (Portman, Natapov and Fisher-Gewirtzman, 2015).

In particular, large gaps relate to content and use cases for understanding, checking, and adapting the technology to suit different user backgrounds, demographics, and cultural perceptions (Jiang and Thill, 2015). Added to this is to extend the period for which collaborative facilitators are involved, for longer sequences, before and after events (AlWaer and Cooper, 2020).

Further discussion is needed on how and to what extent ideas are implemented following SC areas of collaboration, and relating to the testing of collective creativity (Parjanen, 2012). Interdisciplinary working SC needs further testing in broader contexts:

- With more case studies and at different scales, (Alrashed *et al.*, 2015; Nelson and Bobbins, 2017)
- With wider collaborations in different national and international contexts, within the public sector, with different clients and roles (Nelson and Bobbins, 2017).

With more participatory approaches, using multidisciplinary teams, by comparison, with greater range of geographic, social-economic, and political situations (Ataman and Tuncer, 2022).

One often discussed area of clear benefit (highlighted by the covid pandemic), is the potential for spatial computing to enhance remote work, by reconnecting people in 'space'. Though, there is room for greater understanding of how design teams work when producing digital work in separate locations (Nguyen and Mougenot, 2022).

Gaps in Theory – Urban Design, Critical Realism, Spatial Computing

Very little research has been undertaken looking into urban design matters from a critical realist perspective. This entails a need to be critical of our ability to understand and see reality in an absolute, all-encompassing sense. In addition, on seeking to better appreciate 'likely' underlying causal mechanisms of reality, where estimation would be achieved by viewing multiple perspective lenses (see Chapter 3). Evaluating processes of urban design or spatial computing by seeking to understand causal mechanisms has very limited direct precedents. An advanced search, 'beyond library collection' at the University of Sheffield library returned less than 20 loosely relevant results, latest check May 2024, combinations of:

- 'Urban Design', Planning, Architecture, Landscape Architecture
- 'Causal Mechanism', Critical Realism
- Spatial Computing; OR Extended Reality, OR Virtual Reality, OR Augmented Reality

Sources found and used in this thesis have been high-level meta-theory, philosophical or social science discussions, non-specific methodology guidance, or broadly relating urban design/planning with example applications in urban design. There was a strong relationship between urban design, as an activity exploring reality (a physical, social urban reality), and the fundamental capacities for spatial computing to cognitively represent and work with our individual perception of this urban reality (and some alignment to CR). However, for research relating these in specific combinations, no prior research examples could be found to date.

There has been a shift in research interest towards the practical application of SC tools. This is especially the case for the early design process stages (Vosinakis and Koutsabasis, 2013). Although actual testing of this in practice or other live industries, related contexts is generally low. In addition, the technologies see low adoption rates (Delgado, Oyedele, Demian, *et al.*, 2020; Yu *et al.*, 2022). Hence, there is a strong requirement for more in-depth, real-world (live project) analysis and validation (Münster *et al.*, 2017; Yu *et al.*, 2022). Here, challenges also need to go beyond the technical progress, to consider organisational influences, such as the ability of organisations to adapt, provide additional requirements for learning, for equipment maintenance, in addition to perceived technical concerns over investment in tech that has issues of visualisation quality, accessibility, and the ability to facilitate communication (Billger, Thuvander and Wästberg, 2016).

For the software, more can be confirmed on the range of specific design-related functionality, both in overall capability and in terms of user interface design, as well as in virtual worlds themselves. Most of the commercial software potentially suitable for Co.UD use has been built for other purposes (especially consumer media) and repurposed or adapted for design use. Some design software has had SC functionalities added or has been made available via plugins, for example, Autodesk workshop XR, available 2023 (Corke, 2023). More specifically, related toolsets and interfaces need to be understood and further assessed to understand particular affordances and limits in relation to the design process (Bilge, Hehl-Lange and Lange, 2016). The development of SC tools for urban design requires an increased mixture of creative and practical capabilities (Sanchez-Sepulveda et al., 2019). Little commercial software exists that enables VE collaboration: currently only Spatial and Arkio. And those which do, have limitations in limits on creative capability (weak drawing capabilities and resolution).

Software is needed that is more engaging and holistic, particularly to provide more capability at early stages, including co-design (Yu et al., 2022). Supporting this is a need to develop stronger research into databases, type, and relevance of assets and information to support such SC collaborative processes (Wang and Chen, 2009). There is also a need to develop a deeper understanding of sensory abilities. With the visual emphasis of most SC, audio is an less developed area of research, with scope for exploring its influence of sound on collaborative, social interactions within a immersive, place experience (Lindquist and Kang, 2010). Alongside this, is a need to explore ways to better facilitate subtle, non-verbal cues, which can be lost in multi-user multidiscipline virtual environments, and especially where users are physically remote from each other (Hong et al., 2019), and in relation to understanding longer term cognitive effects of collaborating in virtual environments (Yu et al., 2022).

Specific Gaps - Spatial Computing for Co-UD

> *A more holistic picture needs to emerge of how all technologies and approaches combine to influence personal and social modes (Çöltekin et al., 2020).*

Further Testing, verification: in Processes and Communication

Immersion and Collaboration with SC are two key areas of ongoing research focus (Seichter and Schnabel, 2005), which aligned to early stage design, needs to further develop approaches to communication that are fluid and creative (Seichter, 2007b). These aspects also require further testing in the design studio (Seichter, 2015). However, there is also a lack of deeper assessment applied to testing in practical situations (Münster et al., 2017), to undertake studies related to practice contexts (less than 2% of 201 papers from to 2015-2019 included practitioners), and most contemporary research is based on academic contexts only (Stals and Caldas, 2022). Within this context, there is a need to better understand the social factors that influence collaboration success (Van Leeuwen et al., 2018). Including where approaches might fit in the design process, at different stages and timelines, to better understand the potential to initialise and sustain engagement from members of the public. These could include longitudinal studies to better verify the impact of adding these systems to improving places (Gordon and Manosevitch, 2011).

Using SC as a for tool design review (Wang et al., 2019), requires development needs to better include:

- Versatile, all-inclusive approaches
- Align to/better support real-world design and planning workflows, and stages
- Be design orientated - integrate and manage the wide range of design information
- Facilitate organisational management, team and role requirements with relation to professional process, both for in-person and remote working

(Horvat et al., 2022)

Additionally, more comparative research is needed on the benefits and drawbacks compared to traditional physical modelling when used in collaborative, project-applied studies. For example, for exploring whether SC works in addition, or full replacement for exploration using physical models, and to ask what are the specific benefits of remote and local access? (de Klerk et al., 2019). And/or, to what extent there is a desire for increasing graphical improvements to 3D representations? (Matthys et al., 2021).

Summarising Delgado *et al.* (2020), considered a summative strategic understanding, identifying four key gaps.

- Understanding levels of adoption, in different contexts for comparison of discrepancies
- Mapping advancements in other areas of SC that might cross-over into built-environment
- How to make SC more accessible
- Research that informs skills development of those in practice

Adoption - ‘a lot of potential’, but limited uptake

> *“there was a general sense that although the technology is still in its infancy it holds a lot of potential in many fields” (UN Habitat, 2019)*

Through direct immersive communication within and of the spatial experience of a design, areas of spatial computing demonstrate ways to specifically mitigate collaborative barriers (Seichter and Schnabel, 2005; Wang and Chen, 2009; Koutsabasis et al., 2012; Vosinakis and Koutsabasis, 2013).

More than two decades ago, (Simpson, 2001) noted the very limited amount of research or applications (for VR) that related to real world practice in planning (even less for AR). Whilst there is now a significant and growing body of knowledge and applications, AR and VR still do not have a significant influence throughout many areas of practice. Delgado et al., (2020) evaluated literature on the most common use cases for AR and VR, highlighting significant variance in application and uptake. They found no examples of VR surpassing a ‘basic implementation’, and AR being generally a stage behind VR in most of the evaluated categories.

- Engagement: stakeholder/ client via virtual tour, walkthrough - basic
- design, design support - basic
- design review, design sign off - basic
- training and education - testing

Summarised from (Delgado, Oyedele, Demian, *et al.*, 2020), including categories most relevant to Urban Design

Gaps between Real and Virtual Worlds, between Theory and Practice

There is a gap between research lab-based and in-context studies. More research is needed to better understand contextualised applications, whether idea generation is faster and more appropriate with SC (Gül et al., 2013). And, if it is informed by syncing of the immediate, reactive user experience and interactions to pre-existing and a broad range of datasets (that is GIS) (Çöltekin et al., 2020). Broadly identified is a lack of extended evaluation, especially in practical and real-world scenarios (Milovanovic and Moreau, 2017; Münster et al., 2017; Imottesjo et al., 2020).

Similarly, comparing collaborative virtual environments to other 3D collaborative tools, both with and without avatars. For example, to assess how important gestures are in these situation, or the effects of immersive co-presence on level and quality of social interactions (Hong et al., 2019). Further research should be undertaken in more diverse cultural situations, for example, an expanded range of regional contexts (Misius, 2021), to include less well known and for gaining insight into public perceptions around politically sensitive values, such as those around local built heritage (Oleksy and Wnuk, 2016).

Experience, Cognition and Knowledge

There is impact on cognitive idea creation in design process through overlay of virtual and real objects within design context / process (Gül, 2018)

> *"Studies about augmented reality (AR) largely discuss the design of applications and adoption behaviours of the AR system. Attempts to understand user experiences with AR are scarce" (Park and Stangl, 2020)*

This aligns with game design ideas, as there are many further areas for testing users' emotional responses to immersive virtual environments. This includes the opportunity to explore collaboration with game developers to strengthen design and planning considerations in available applications (Potts, Jacka and Yee, 2017). It also includes ways to assess the importance of types and levels of feeling present (or 'presence'), as well as testing the capabilities of a wider range of systems and models for this. Furthermore, it will be useful to test a more extended range of environmental change options (i.e. light/weather conditions). This could also be tied together into narrative experiences designed to deepen emotive connections (Felnhofer et al., 2015) and to further assess the impact of and for analysis of creativity in the design process and how this might vary by different scales of design, that is, from urban design to interior design (Özgen, Afacan and Sürer, 2019). Similarly, for better understanding design users' movement and experiences, for example, in understanding pedestrian navigation behaviour (Natapov and Fisher-Gewirtzman, 2016).

Relating to geo-located AR placed in the real world, there is scope to explore beyond participatory processes and to engage people in activism (e.g. Local Media Interventionism). This could help to further understand requirements and aims for interface design towards improving social inclusion and engagement, and to understand this by importing knowledge from other disciplines such as behaviour economics and social marketing (Khan, Loke and Khan, 2017). Taking their cue from ecological psychology, Raja and Calvo (2017), argue that more can be done within the common areas of research, such as improving technical issues (e.g. "parallax errors, latency"", "occlusion"), or device marketing ("easier, efficient", etc.). More specifically, they indicate a need to better understand how these broader technical and social issues may further impact on individual users cognitive load. Such understanding of spatial cognition still requires repeated and larger studies, with more participants (Buhmann and VDE Verlag, no date).

Increasing Stakeholder Diversity

Many SC systems are still emerging and have seen a limited range of application. This presents a need to test conditions with increased diversity of collaborators, including the public (Imottesjo et al., 2020; Imottesjo and Kain, 2022), and to include experts outside of common collaborative teams (Gill and Lange, 2015). Similarly, testing with more demographic diversity of participants, varying age and gender groups (Liao and Humphreys, 2015). Such exploration through negating equal opportunity and inequality issues could reduce the gap between those who make decisions and those who are influenced by them. Further testing of collaborative design environments could involve those beyond design teams (Chowdhury and Hanegraaf, 2022). Within these aims, claims, such as 'easier access' and 'ease of use' need to be tested with broader range of, non-expert participants. For example, as Imottesjo and Kain (2022) highlighted, moving on from initial testing within specific areas of application and functionality can be successful with a broad range of stakeholders and opens more nuanced areas for testing.

There is a need for collaborative control of the design process by various participants, with visual/graphical illustration to support learning-interaction with the technology, which is aligned to users' individual position in the 3D space (Calixte and Leclercq, 2017). Connecting such local issues to strategic issues, might allow greater understanding to be gleamed on the processes and feelings of stakeholder empowerment. It might also allow exploration of potential ethical implications, such as individuals' perception of reality, political persuasion and control, facilitated by increasingly powerful immersive narrative capability (Liao and Humphreys, 2015).

Technical development required for Co-UD

Though the aim of this study is not focused on technicalities per say, the literature and grey sources do present an overall focus on it. Large amounts of research literature related to spatial computing (SC), (for Co-UD) starts with the premise, or greatly considers the further development and testing of specific technical improvements in areas of SC, which relates to a wealth of identified gaps–improvements. There is also a tendency to discuss, in broad terms, and present gaps that focus on hardware requirements, with software, specific usability, and interface design often being secondary. Similarly, as discussed, these improvements are often implied to lead to general development in capability and usefulness to co-design (or *perhaps* assumed, proposed, hoped). Taking the body of discussion, a 'how do we do this?' seems to be a more common focus. What this research aims to focus on is re-question 'do we actually need this?' / 'what impact might it have in the long-term?' However, the current technical gaps somewhat limit our ability to answer these kinds of questions fully and need to be understood to move forward.

Recent work has called for a better understanding of the strategic and integrative requirements for improvement across systems, a more holistic design of the systems (hardware and software), including adaptability to different collaborative contexts. Broadly, the rationale for technical improvements was presented as for increasing use by improvement to the user experience (Fonseca, Redondo and Villagrasa, 2015), which includes improving compatibility between formats (Fonseca et al., 2014), and generally more solid reliability and adaptability to different uses (Fonseca Escudero et al., 2017). For example, the development of more advanced interactive capabilities and connection to online data and resources will support public participation approaches for AR (Reinwald et al., 2014) and VR (Fares, Taha and EL Sayad, 2018).

With the ongoing development of new technologies for urban design, there needs to be an integration of improved graphics quality and range of application (Sanchez-Sepulveda et al., 2019). More also needs to be understood regarding collaboration as a dynamic system and how SC systems user interface (UX) might be uniquely designed to support this in sophisticated ways (Wang et al., 2019). The limited range of software currently available for immersive co-design lacks much of the advanced feature sets from a vast range of more established software, for example, parametric modelling or simulation modelling for contextual analysis (e.g. financial, microclimatic, pollution, traffic) (Yu et al., 2022).

Interface Design

A more systematic, comparative evaluation is needed to define the overall requirements for the effective and efficient operation of systems within collaborative processes (Misius, 2021). User experience design principles need to be explored for Co.UD in relation to

- Be Intuitive from the user's perspective

- Seamless transition of digital systems: translating files and formats ('BIM to AR')
- Capability of the system to continuously read and position digital artifacts within physical surrounding context
- Functioning seamlessly, irrespective of the various types of supporting network systems/devices

(Chen and Xue, 2020).

Summary

Further testing in a wider range of real-world situations is required to understand the wider issues and influences at play. There appear to many benefits that spatial computing can bring to co-urban design; however, we are not certain on the extend and scope of this usefulness, when considering the range of design contexts, different disciplines involved, intention of the various types of designers and planners, not least the highly various members of the public.

Research gap

Significant gaps remain in understanding the role of spatial computing in urban design, despite increasing research being undertaken (Çöltekin et al., 2020; Ataman and Tuncer, 2022). A holistic methodological framework to understand SC within complex real-world contexts, such as interpersonal and wider social and political factors, is lacking (Araabi et al., 2017; Lang, 2005; DeLanda, 2019). Contemporary studies have increasingly focused on technological developments to replicate or build on existing urban design methods. However, broader claims regarding the benefits of SC require real-world testing (Carmona, 2014; Black and Sonbli, 2019). In the last five years, spatial computing hardware/software has become increasingly available as off-the-shelf products (Gill and Lange, 2015). This has made real-world testing increasingly possible, particularly because it is cheaper and requires less advanced human and technology resources. Simultaneously, theoretical uncertainties are still present in the transformative potential of the design process and practice, raising various ethical concerns regarding the nature of discipline work (Koutsabasis et al., 2012).

This project aims to contribute to a more holistic evaluation of these contexts to better understand the social aspects of collaborative work on urban design decisions. This is achieved through a series of reflective interviews with urban design practices, a local government group, and live testing of SC by students through events which simulate practice conditions and contain practice and public stakeholders.

4 METHODOLOGY

This chapter presents an account and rationale for the system of methods used to gather primary data for this study, explaining the relationship between theoretical basis, research questions, and practical research design. The research design sought to explore the potential increasing influence that spatial computing might have on the collaborative causes and effects of urban design. As outlined in Chapter 2, the 'Urban': is a physical and social place, our human habitat, that interacts with our bodies and minds. It's processes of formation and adaptation are mostly applied at the early stages of built environment process (Black and Sonbli, 2019) and are driven by social (political) influence (Lefebvre, 1991), i.e. as implemented through planning > design > construction > reflection, as tangible and intangible forces, evident in in the relationships between objects/spaces and subjects/people (as Assemblages) (DeLanda, 2019). These intertwined causes and effects, require collaborative design effort (Lang, 2005). Hence, urban design is a conceptual, holistic process that aims to cover a broad spectrum of transdisciplinary interests (Carmona, 2014).

Aligning to this condition, the research events engaged a range of participants in conceptual urban design actions and/or reflections on urban design contexts: as the earliest design stage of a more extensive built environment process. Thus, research activities engaged participants in conceptual, or strategically focused areas of design exploration, where participants perceived:

- the design task –*interpretation based on experience and philosophical/cultural position (e.g. outline, framework brief)*
- perspectives – *reformation, active search for new ideas, criteria, visual-semantic (e.g. context analysis; site, social, stakeholders)*
- new semantic combinations – compositional exploration and comparison *(e.g. concepts)*
- new solutions – choosing design version, developing *(e.g. prototypes, refinement)*
- users' reaction – feedback from others outside of the process
- cyclical feedback loop to further refine the task, OR define a follow up task

(Tschimmel, 2011) *authors examples are added in brackets

4.1 Overview

Data were collected using a combination of qualitative methods involving a range of transdisciplinary experts and non-expert participants and students. Methods were used separately in sequence and in overlapping combination, aligned to specific contextually unique cases and activities: as 'Events'. Most data derived from participant reflection on past events (interviews/focus groups) and/or perceptions relating to the live events (audio-text transcripts). This was supplemented by researcher observation of these live actions (as written notes), and/or through review of video footage. In addition, participants tangible design outputs were collected and provided a summarised conclusion on the overall design process and proposals (as drawings, diagrams, photos, writing, etc.) combined as a 'design portfolio'. Broadly, there was also the intention to capture social conditions that influenced design actions, decisions, and outputs.

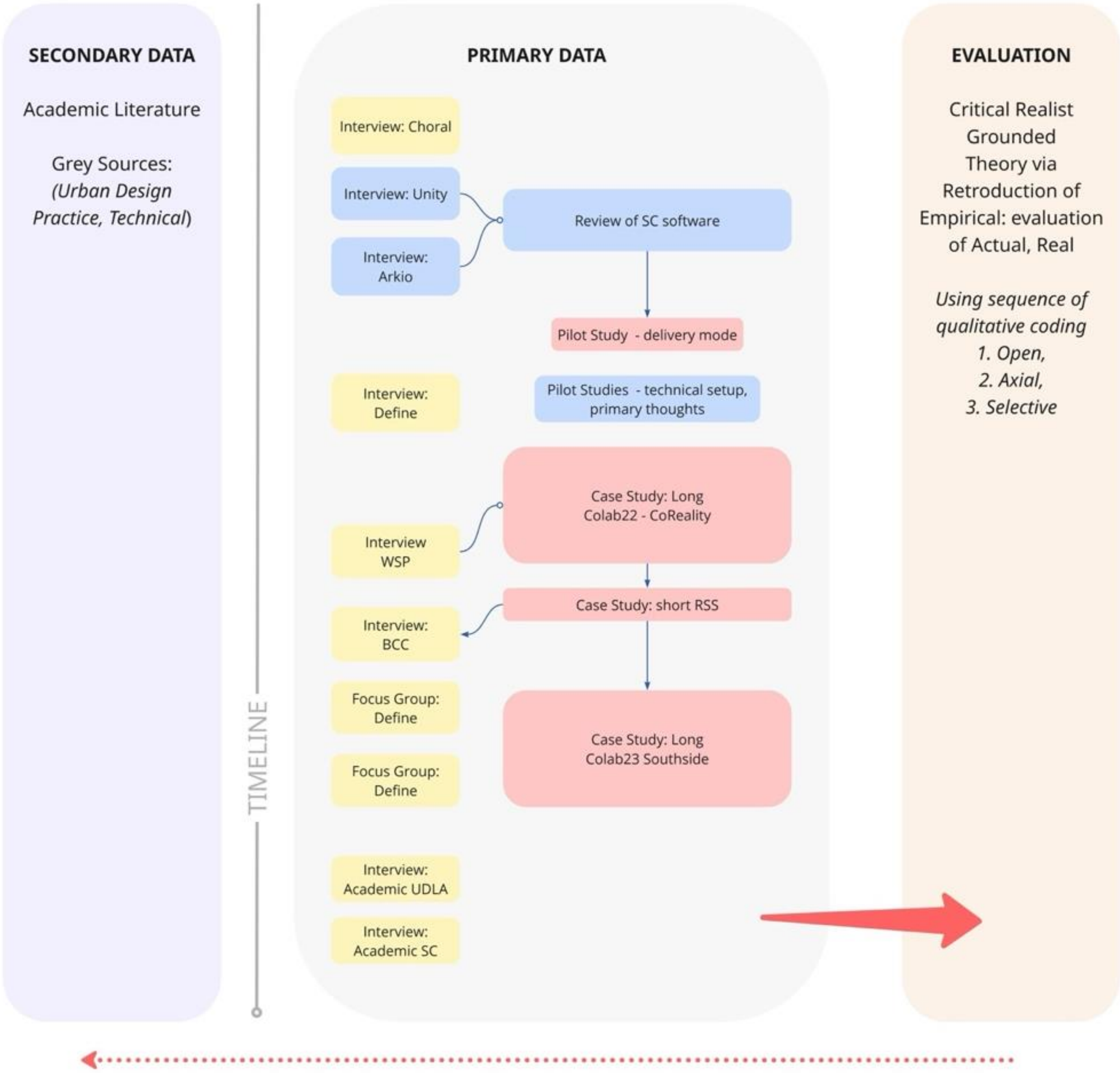


FIGURE 19 - RELATIONSHIP BETWEEN DATA COLLECTION ACTIVITIES (AUTHOR)

Table 5 - Actions / Perceptions

Perceptions:	Expert reflections on their past experience	Interviews / Focus Groups
	Participant reflections on their recent experience of case study activities	Design Events ('live' cases)
	Researcher as participant, reflections on engagement in case study activities	
Actions:	Participant created data: visual, audible, and written design artefacts	
	Researcher engagement in and observations of the event	

Relationship between data

Within each case study, specific mixed methods aimed to triangulate (Creswell, 2013, p. 251) the perceptions and actions of participants (Jaswal, 2016). This collated participant produced mixed-media data such as text, drawings, models, and notes, in virtual-digital and physical formats. The production of this 'design associated information' was also often by observation as an event by the researcher, who took notes and drawings of participants' engagement in activities, including as reflection on level and type of interactions. Survey and focus group activities collected participant reflections on their experience.

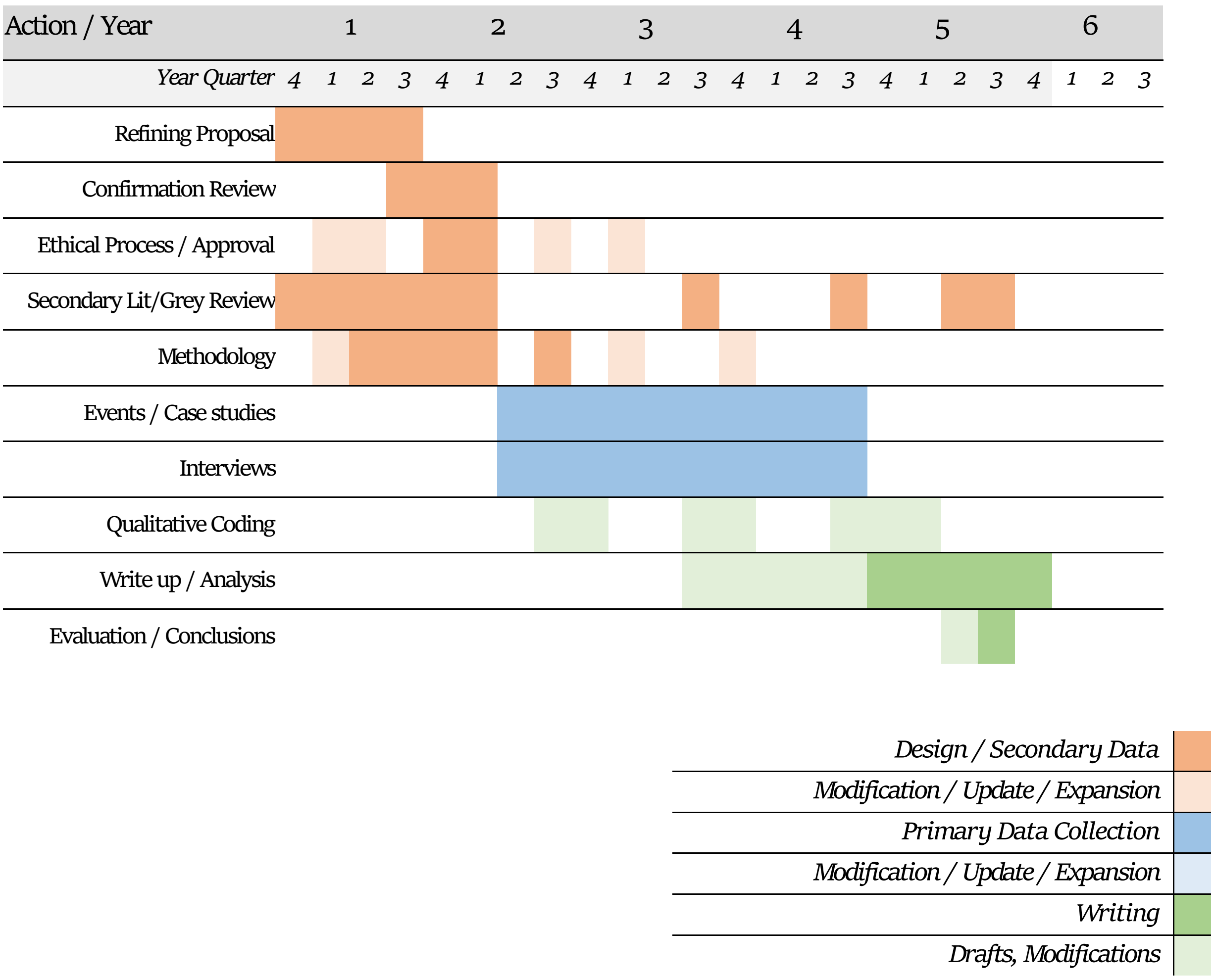
Analysis of the resulting large qualitative dataset (primarily text) was analysed through iterative stages of qualitative thematic coding (tagging and categorising), though with care to retain their contextual interpretation. In this process, initial open codes were formed to define thematic groups and eventually into broader topics. These themes formed the order of evaluation with relation to the research questions, as seen in the Discussion – see chapter 6. The specific context and further details of methods are summarised by introduction at the start of each data event (see Chapter 5: Results).

The following subchapters provide further explanation on the underlying method types outlined thus far.

Timeline

As a part-time undertaking, the timeline of the project followed an extended but also somewhat sporadic process. This provided benefit to align with deeper understanding on the emergent nature of subjects, from a greater range of research literature; development spatial computing hardware/software capability/accessibility; and changeable contexts of real-world urban design. This presented a benefit to appreciating and communicating a narrative over a more extended timeframe than might otherwise be typical to shorter researcher projects or full-time PhD research.

TABLE 6 - PROCEDURE AND PROJECT TIMELINE



4.2 Literature Review - Current Knowledge

A review of secondary sources aimed to position the contribution of this study within an emergent conceptual framework, which was further examined through primary data collection. Secondary review chapters (2,3) provide a broad introduction to many layers of context for research. These are presented as a narrative of increasing focus, moving through three core topics: Urban Design (early stage/strategic/conceptual, design activity) > Collaborative Design (social approach) > Spatial Computing (technologies). The first outline of contextual topics (2) led to and formed the foundation for the critical review chapter (3), as a basis to then discuss the most contemporary papers of relevance, as the *state-of-the art* (Sutton *et al.*, 2019). This positions the specific areas of existing knowledge on spatial computing for Co-Urban.

- Chapter 2 – presents an overview of key topics, defining key terms and descriptions of Co-Urban Design and spatial computing, and a summary of the key philosophical underpinning of the research.
- Chapter 3 positions the research problem within contemporary areas of knowledge and debate.
- Combined, these chapters support the rationale for this methodology – Chapter 4.

The secondary review chapters were based on a combination of initial wide reading, followed by thematic analysis using qualitative research 'coding' (categorisation). This aligned to broader theory development as described previously in 4.2. The secondary data review was undertaken in a longitudinal way, completed and updated alongside the conceptual development of the thesis, that is, initialised before, iterated alongside, and updated after. The primary data collection fits a narrative account produced by a broad reflexive thematic analysis (Braun and Clarke, 2022, p. 121). This approach was used because of the still emergent nature of accessible spatial computing, which still sees dynamic changes in availability and capability, and for which strengths and weaknesses are significantly debated, not entirely established.

Through primary and secondary data were coded using separated processes of analysis, themes were later compared as they emerged from primary data analysis (constant comparison). Secondary sources related to the technological context for SC, were highly emergent and often presented factors not yet specifically covered in research literature, entering existence alongside the part-time extent of this PhD project.

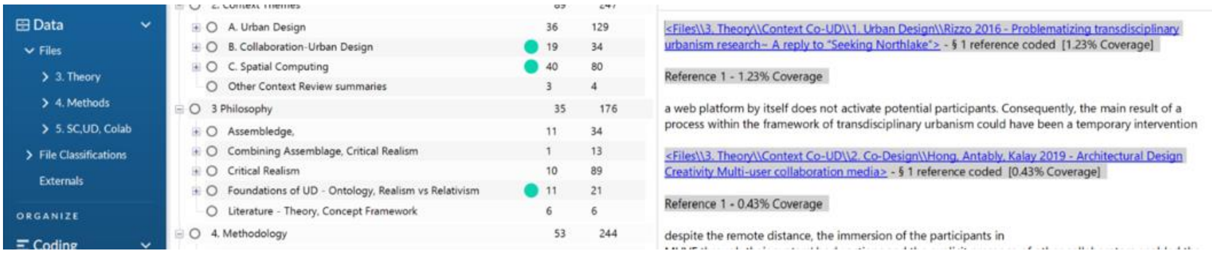


FIGURE 20 - CODING SECONDARY DATA – EXAMPLE IN PROGRESS 01/2023

Key Search Words

The following key words/combinations have been used in searching for references using university library databases: *Starplus, University of Sheffield, Birmingham City University Library, as well as searches including Google Scholar, Research Rabbit, Lit Maps, Connected Papers, and Elicit*.

Initial searches used the three main broad topics of study, with subsequent combinations of related words:

- Urban Design: Urban, Architecture, Landscape Architecture, Planning, Urbanism, Built-environment, Design Process,
- Collaboration: Co-Design, Participation, Engagement
- Extended Reality, XR, Augmented Reality, AR, Virtual Reality, VR, Mixed Reality, MR, Immersion/Presence
- Space, Place

Review of Secondary Practice ('Grey') Sources

This study was situated between the themes of theory and practice and required sources other than pure scholarly research studies. While this was fundamentally underpinned by theory through analysis of research literature (theoretical and analytical debate), the nature of the project's contextual themes related strongly to specific developments, as well as critiquing the relationship between the two, as follows.

For Urban Design practice, useful information was derived from practice and/or public facing documentation and often related to specific, place, and project-based contextual understanding of a kind that was either rarely recorded in academic sources, and/or was changeable to the point that research processes had not kept pace. It was necessary to appreciate the context of the opportunities presented by the new hardware and software availability as they become available. For spatial computing technology, which is a highly emergent area of technological development, the requirement for using non-research-based sources was particularly important for gaining appreciation of the context for study, as well as informing the practicalities of research design. The speed of technical development in this area is often not directly aligned and/or, in some cases, vastly outpaces the processes of case-applied research, particularly relating to use cases in urban design.

4.3 Methods of Primary Data Collection

Data were collected in two primary ways and in specific sequence of contexts and events, as:

1. Interviews/focus groups (stand-alone) - Statements and reflections were collected from professionals undertaking urban design, software development, and/or academic researchers
2. Case study: 'Events' - Mixed-methods, primarily audio-visual recording/transcripts, observation, as well as interviews/focus groups captured live reflection on early-stage design process activities (a design project/process), related to urban design strategy, conceptual visioning, stakeholder-public participatory and exploratory activities.

Deeper contextual introductions to each data collection activity are provided within at the start of each sub-section within the results chapter (see – chapter 5). The overall data collection sequence started with exploratory and pilot studies to test and refine technological and research methods, and to confirm broad understanding. This was followed by much deeper application within longer timeframes of following main events, which used real-world aligned contexts (Lucas, 2016, p. 12). This range of practice/place located methods was used to maximise variation for broader evaluation, while still providing contextual focus (Flyvbjerg, 2006).

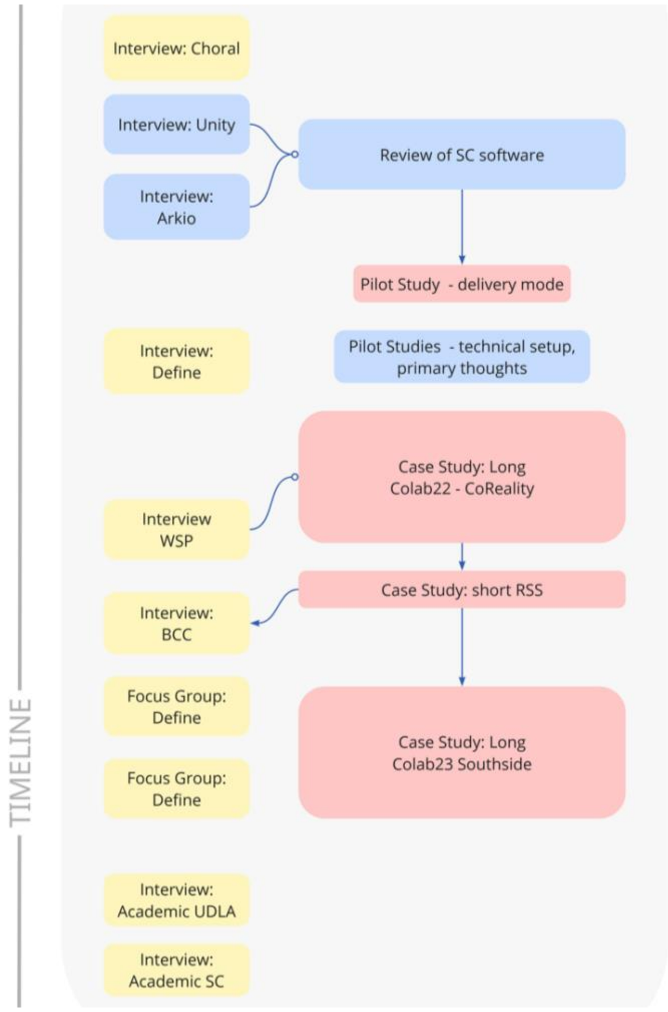


FIGURE 21 – PRIMARY METHODS IN SEQUENCE

Data Collection Events

The following tables (10) provides an overview of the data collection event context, with relation to aim and method. These are presented by a broad method type, and then chronologically.

TABLE 7 - OVERVIEW OF THE DATA COLLECTION EVENTS

Timeframe	Event / Context	Aim / Content	Specific Method(s)
FOUNDATION PRINCIPLES / EXPLORATION & TESTING			
2021 - current	RESEARCHER REFLECTION Prior knowledge and experience	Define researcher's key design practice and academic experience of Co-Urban Design; Spatial Computing	Reflective Writing
Throughout	RESEARCHER REFLECTION Developing knowledge and experience	Explore research design/ decisions, theory, within and post-events, stand-alone reflection, and/or live	Researcher notes Audio recording
2021 primarily - *updated to 2023*	TECHNOLOGICAL EXPLORATION / TESTING By Researcher, testing, analysis hardware/software	Analytic review of spatial computing hardware/software testing/preparing technical setup. explore and test: assumptions, key methods.	Researcher observations and notes
INTERVIEWS/ FOCUS GROUPS – STANDALONE			
2021 Dec 1hr	SOFTWARE DEVELOPER Unity Reflect/Review software	Software for review of architectural design (AEC), which includes AR/VR support	Semi-structured interview - online audio-video recording
2021 Dec 2hrs	DESIGN PRACTICE Choral Studio, UK and China	Specific practice application - VR for regular international concurrent virtual design	Semi-structured interviews - in-person, audio recording
2022 Feb /Jul 2x 1hr events	SOFTWARE DEVELOPER Arkio.io – with Head of Product	Design aims, objectives and direction of commercial software - AR/VR/desktop collaboration virtual co-design	Semi-structured interviews - online audio-video recording
2022 Jul 1hr 2023 Aug 1.5hr 2023 Sept 1hrs	DESIGN PRACTICE with Define Ltd (Planning and Design Practice)	Specific practice application, experience and reflection on using: AR system 'True View'	Semi-structured interview/focus group - in-person and online, audio recording
2022 Jul	LOCAL COUNCIL Birmingham City Council, planning team: 6 members	Reflective discussion on their strategic uses of SC, aims and constraints	Semi-structured Focus Group / Interviews–audio-video recording

2022 Nov	ACADEMIC Vis-Com, & SC	Broad discussions on applications within design, future potential and ethics	Semi-structured Interview – audio recording
EVENTS – CASE STUDY / DESIGN ACTIVITIES			
2021 Nov, 2hrs	SHORT - STUDENTS Undergraduate BA Interior Architecture	Conceptually explore themes, test basic AR software on personal mobile devices	Focus Group - Audio recording, Chat, Survey
2022 Jan, 3hrs	SHORT - STUDENTS Undergraduate BA Landscape Architecture, and BA Design Management	Conceptually explore themes, current and future potential, test VR Arkio/Google Earth	In-person observation Focus Group - Audio recording
2022 Jan-May 10x 3hrs	LONG – STUDENTS AND STAKEHOLDER CoLAB Co:Reality Brum – student and practice: WSP (Design and Planning Practice)	Exploring and testing themes over a 12-week practice and place connected, practitioner and student-led design collaboration. VR Google Earth, AR Spatial, student developed bespoke app, using Unreal Engine	Video / In-person observation, Participant design outputs, Semi-structured interview (key stakeholder) / Focus Group – audio-video recordings, Researcher Reflection
2022 May, 3 hrs	SHORT - STUDENT EXPLORATION VR MA Landscape Architecture	Test 'free' design in VR, as well as live testing of software Arkio and Gravity Sketch and hardware Quest 1, Rift S in playful, explorational ways	*Mixed Qualitative /Quantitative Survey reflective *Video / In-person observation
2022 Jul 5 hrs	SHORT - PUBLIC PARTICIPATION 'Re-imagining Southside	Testing live use of accessible AR system for participatory design objectives. 2x repeating events with new groups	* In-person observation *Focus Group / Interviews–audio recording
2022 Jul 1 hrs	SHORT – 'SUMMER SCHOOL'	Broad perception of spatial computing by international participants	*Focus Group–audio recording
2023 Jan-May 10x 3hrs	LONG – STUDENT AND STAKEHOLDERS CoLAB 'Re-imagining Southside. Southside BID, manager, public participants	Exploring and test themes over 12 weeks, academically driven collaborative live project context, including in-depth exploration of Arkio / Mobile VR collaboration	*Video / In-person observation *Participant design outputs *Focus Group – audio-video recordings *Researcher Reflection *Semi-structured interview (key participants)

Interviews / Focus Groups: Practice

Interviews were undertaken with specific participants, both independent from and involved in the main case studies, of varying time limits depending on the availability and context of the interviewees. This gave a broad account and a range of perspectives on general current and future expectations. For built environment practice, this provided understanding of different design objectives and how these relate to certain desirable attributes for spatial computing. From the software developers, this indicated ongoing aims, considerations of target audience, and relationship of spatial software-hardware design to built-environment objectives.

TABLE 8 - INTERVIEW/GROUP PARTICIPANTS

Who	Number of Participants	Type	Length	Date
Choral Studio (urban design practice)	2	Interview	45 minutes	25-11-2021
Unity (software developer)	2	Interview	30 minutes	01-12-2021
Arkio (software developer)	1	Interview	1 hour	01-02-2022
Define Limited (urban design practice)	1	Interview	1 hour	09-03-2022
Urban Design lead WSP - *connected to CoLAB, Co-Reality Brum, but also wider discussion*	1	Interview	1 hour	17-05-2022
Birmingham City Council	5	Focus Group	1 hour	18-07-2022
Visual Communication Spatial Computing Academic	1	Interview	1 hour	13-06-2023
Define Limited (urban design practice)	10	Focus Group	1 hour	22-08-2023
Define Limited (urban design practice)	13	Focus Group	1 hour	13-09-2023
Landscape Architect/Urban Designer Practitioner-Academic	1	Interview	40 minutes	10-01-2024

Qualitative data were captured using audio recording for group (focus groups) and individual (interviews) experiences (some online were video capture, but only audio was used). Both used a sequence of open questions were used to allow participant driven data (Creswell, 2013), though with some prompts towards research topics: i.e. on the influence of SC on:

- Success of the collaborative process
- Success of design process
- Feelings of participation and inclusivity within the project
- Level of engagement with design, collaboration and/or technology
- The benefit and drawbacks when using spatial computing hardware, software, compared to other methods and participants' wider experience, knowledge beyond the live events

An open, flexible approach allowed focus on gathering of experts' defined points of reference rather than forcing preconceived topics of discussion (Creswell, 2013; Roberts, 2014). At the same time, the above questions were in the mind of the researcher to provide a broad framework, acting as reminders, for guiding follow up questions. Though, were often asked more specifically, in relation or reaction to discussion as it happened in the interview or focus group (as a reflexive approach). This approach attempted to avoid forcing the researcher's interpretation within the questions, but letting the participants speak openly (Vanderstoep and Johnston, 2009).

Further details of the interview/focus group participants are covered in section 4.5

Topics, Questions and Direction

Data were generally attained with focus on participants experience of spatial computing, as prior: aims and expectations and/or post: experience reflections - measuring and assessing viewed success. Questions were not asked directly or in a formal manner, but were in the mind of the researcher, asked and adapted in relation to the fluid discussion. Often this was in more specific ways that reacted to interviewee defined threads (Maxwell, 2016, p. 236). The questions were also asked in the context of already knowing about the research topics and participant's level of interest in spatial computing. The following questions were on-hand to the researcher, to prompt and remind if the discussion had covered appropriate ground:

- What is the overall approach of your business, or practice/office? (philosophy, aims, etc.?)
- Would you say it is driven by the client in terms of what they want? that is, they have got an aim, and then you work out how to…?
- How do you tend to work with your clients?
- How is your practice set up?
- How do you communicate design ideas?

Events: Co-Urban Design Projects

Sequenced conceptual urban design exercises were undertaken to explore transdisciplinary and public participatory means. Events engaged student participants studying Urban Design, Architecture, Landscape Architecture as well as key stakeholders (all events) and members of the public (5.5, 5.6 only). This included various types of SC within early-stage urban design process, i.e. conceptual, strategic, design vision (e.g. as discussed in Chapter 2.1). Design briefs were directly aligned to and guided by key expert stakeholders from practice and/or local public stakeholders ('project partners'). As such, they these participants greatly informed the broad appreciation of context, e.g. wider practice aims, planning policy, local politics. Stakeholder participants were also involved in directly within the project for guidance, and reflection of student process.

Initial pilot research phases quickly tested the broad theoretical position and alignment/suitability of the research methodology. Outcomes informed more refined use in the more substantial and data novel activities that followed. As the research phases progressed, methods were tested within projects of increasing extent, complexity, collaboration, and design value expectations.

TABLE 9 – EXAMPLE METHODS IN RELATION TO EVENTS

Stage	Method
Pre-design-project	Presentation with open discussions (focus group)
Open questions on: perception, familiarity/use sc, knowledge of / expectations for: transdisciplinary collaboration, participatory design and planning, *e.g. Non-leading questions:* *What are your thoughts on augmented reality? What are your thoughts on using virtual reality in this use case? (not: do you think sc tested is of benefit to urban design?)*	
Within design-project	Visual outputs from design activity, audio – notes transcripts, commenting on design, observation and notes
Praxis of participants: modelling, mapping, drawing / speech - writing, post it, notepad / *researcher notes and drawings of event / actions*	
Post design-project	Interviews / focus group / survey
3 thematic groups within overall collaborative group: reflective, 3 qualitative questions Background and expectations, experience and outcomes	

The literature review recognised that an unrepresentative amount of transdisciplinary research takes place in single-user, and/or lab-based studies (Gill and Lange, 2015) and entirely academic situations and contexts (Rizzo and Galanakis, 2017). Whilst acknowledging an increasing body of examples, there was still great scope both for new applications, the further testing of methods in new or alternative contexts. Whilst the initial intention for the project was to move to situating events in live practice conditions, for example with the practices interviewed (see previous section), issues of organisational complexity and sensitivity proved ultimately difficult to agree and arrange within the scope and timeline of this research (see 6.4 Limitations and 7.3 Further research). Therefore, the design projects were situated within real places and with real people, as live cultural/physical context, as a thematically and practically close-academic simulation. This took advantage of increasingly mobile and accessible methods of SC, to tested approaches with regular engagement in and of dynamic, real-world, collaborative contexts (Wang and Dunston, 2013; Çöltekin *et al.*, 2020).

Participants were engaged in the review or production of live, collaborative urban design process and outputs, e.g. towards drawings, graphics and discussions which represented their perceptions, design intent/actions. The events ranged in context, time frame and level of involvement and task/objectives, from minor studies of 2-3 hours to repeated sequenced sessions over several months. The details of such, are specified more fully in the introductions to each event (e.g. subchapters 5.4-5.6). Each project involved transdisciplinary collaboration as a direct design activity, or reflection over an extended timeline (over several months). They included the use of and experience with digital and physical design tools, including the use of augmented and virtual reality (AR & VR) hardware/software and reflection on current and future capabilities with relation to the idea of a convergence of these capabilities as 'spatial computing'. For all these live events, data were collected both during the process, e.g. as live capture of actions and discussions, and as reflection on the events.

Reflective Survey (post-event)

A short survey was made available to participants in conclusion of the live collaborative events, using a digital online form (Microsoft forms). Data collected from this method was a minor contribution, less than 5 replies in total, but added to the overall data set. This slightly contributed to widening data capture, collecting comments from those not able, or not wanting to discuss in focus groups, or for those wanting to add additional comments after the event. This method was intended to prompt from similar questions (discussion points) as those from event focus groups. The form used the following questions.

- What was your overall experience of using AR and VR in the design process?
- What is your design process? What steps are involved in this process?
- Did it influence: add to or detract from the design process?
- Did you find the process with AR/VR better or worse than the traditional methods? - why?
- Did you note any specific issues or benefits?
- Were you able to communicate in better or worse ways compared to traditional methods? – how? – why?

Design Outputs (artifacts)

Visual and written design information was collected from the participants' mixed media portfolio of outputs. There will be participant-driven flexibility in what they may create, but this will likely include collated images (e.g. photos, drawings, graphical outputs: diagrams, maps), 3D models/objects, videos, and reflective writing. It can be captured in digital, physical, SC digital, and hybrid formats.

Design Data, comparing types and mechanisms of outputs. The code categories will be confirmed from retroductive analysis, but for initial example: facilitating design process in terms of speed, depth of character conveyed, level of co-production. The process of this production was observed by the researcher, who also took notes, diagrams, and photographs of the event and who was also a participant; hence, sometimes in collaboration with participants in producing outputs.

Spatial Computing resources for Events

For this research, the SC systems were iteratively reviewed by the lead researcher before selection for each case study and updated as the project developed. The evaluative categorisation of these systems was driven researcher review with relation to urban design theory and practice experience. Selected applications were further tested in design process conditions by the participants as hands-on experience.

Spatial computing is an emergent area of technology; therefore, its hardware and software landscape changes frequently. Convergence and increasing computational power (Liao and Humphreys, 2015; Mota et al., 2018) across a spectrum of systems, continued to develop in terms of graphical capability and public accessibility, through the project, but choices were limited, both as a choice to aid in consistent approach, and due to limitation of resources – use of available equipment.

Spatial hardware devices

- Oculus Rift S (now Meta Quest)
- Oculus Quest 1 and 2 (now Meta Quest)
- Apple iPads
- Various participant owned personal Apple and Android devices (not logged)

The range and subsequent choice of a narrowed selection of software for live testing is discussed more extensively in subchapter 5.2, though summarised as:

Primary Spatial Software

- Arkio (Desktop and VR)
- Google Earth VR (VR)
- Augment (AR)
- Thyng (AR)

4.4 Participants and Selection

The mix of participant types differed between interviews and events. Where interviews involved urban design, or software development related professionals, the events involved transdisciplinary undergraduate and postgraduate students studying Urban Design, Architecture, Landscape Architecture, as well as some professionals, and some stakeholders (including members of the public, often in groups). The technological/methodological pilot studies also involved some Interior Architecture and Design Management students.

Members of the public were involved for two of the main events, either via direct signing-up in response to an advert, or through engaging in specific student place-based public-participation exercises (as 'participants or participants'). Student participants were involved by sign up to specific module by subject association. For the live, design events, the student participants self-selected their inclusion via choosing to join an options-based module (though additional consent was also confirmed). Professionals and stakeholders were involved following direct contact by the researcher or by association with the event/context. They were selected due to their known knowledge/experience on the research themes by the researcher. This related to an action research approach, aligning 'live' events, projects, or networks of shared interests. Those involved in these projects were aware of the research aims in advance, most of whom became consenting participants. Participant contact, in these ways often aligned to long-term, ongoing professional relationships with the researcher, by new association with established topics, context, or real-world events. Hence, participant selection was largely non-random (Vanderstoep and Johnston, 2009, p. 27), except for public participants engaged in students 'public engagement' activities as ah-hoc engagement on site, in live public context.

The researcher's professional practice, as an urban designer, landscape architect, and academic lecturer (and manager) played a significant part in the creation of, or access to participants and the research event (design projects), as sources of participants and data collection. Participants were in majority of an architectural/urban design background (except members of the public) and either practitioners, academics or students, with alignment to the project or context under study, or were contacted by the researcher due to direct relation with spatial computing with relation to built-environment practice/study (e.g. Arkio, Unity).

For most participants, the research aims of this study were not the focus of their engagement, but a side element to other activities (the event, research context), such as completing a design challenge, discussing their ideas about the subject, and developing their approaches. In this way, the nature of the participant 'selection' process varied greatly in ways that are detailed further for each data event (see the introductions in 5.1~5.6).

In addition, the researcher is also considered a participant, where the critical realist view is that it is also impossible to entirely separate oneself from influence via 'objective separation' (for example, (McNiff, 2017, p. 37)). This is rationalised and summarised to follow and presented throughout further accounts in the results chapter, *Reflection on experience* [see 1.6]. Relating to the interest in strategic themes, and particularly collaboration, participants are generally considered a holistic group, rather than an individual focus. However, clearly some individuals did contribute more significantly through repeated and/or more extended periods, as evident in the data set (see 9. Appendix).

Broadly speaking, the participants were considered part of the following practice aligned groups.

- Urban Design 'Practitioners', which includes those in practice, in teaching of, or as students of these disciplines
    - Designers: Urban Design, Architects/Landscape Architects
    - Planners: including specialisms
- Stakeholders: The Public (as end users), and/or those working in areas of Government or regulatory bodies, acting as 'Clients' and other stakeholders
- Specialists in spatial computing, though knowledge/experience

Participant recruitment in most cases was through prior and/or embedded involvement in case study contexts (e.g. they were affiliated to place, design practice, or were students engaged in the events), were already known professional contacts, or in some specific cases were contacted by the researcher (/myself) as having potential interest in being involved as a participant.

Practicing designers & planners

Practitioner participants were defined as those who had a combination of practice-applied experience and recognition in areas of urban design practice, beyond study, or academic work. The participants fell into two broad categories: designers with a focus on the production process and planners with a focus on strategic policy and proposal review. No form of controlled selection was undertaken, as stated previously; rather, the research activities related to events that these practitioners were either already involved in, or had responded to proposal, or themselves proposed to discuss the research themes, broadly this occurred in ways that I presumed were also of benefit to their practice. As an example, a focus group (online meeting) with a team at the Birmingham City Council planning department. Various members of the team shared professional interests in reducing gaps for public engagement through digital technologies. Following one of the teams' involvement in a prior activity (public participation), they were keen on the ideas and followed up with wider team discussion, resulting in my subsequent invitation to discuss with the wider team (focus group).

In the case of practitioners, there was no attempt to artificially craft an ideal team, but rather, the exact makeup of practitioner types and groups varied by each data collection event, as they were not representative but were the actual makeup of a real-world practice team or network. While it was not an aim to survey individual backgrounds, it was clear that different people brought specific knowledge, experience, and perspectives (agendas) with areas of broad understanding, individual specialist focus, and with significant, varying overlaps between.

Spatial Computing Software Developers

Specialist SC participants provided insight into the organisational approach, technical capabilities, and further aims of companies working in these emergent areas of technology. Two different companies of different scales became participants, one representing a very large, established company and the other a new startup. An element of the interaction related to sales, and was not avoided, but considered a realistic type of interaction, a connection between potential new software for the university, for them to potential client (university with many students). The realism and exploration of the influence of this social-contextual setting allowed for an element of potential deeper inference relating to aspects of power and structures that formed useful context relating to the research objectives.

Students

Student participants on the one hand represented a highly diverse spectrum of people (cultural demographic, perspectives) and on the other hand a quite limited one (generally – very educated, strong educational attainment, of certain wealthy, and specific age range–though with several exceptions). The student participants sat along a broad, varying spectrum in terms of skills, knowledge, and/or experience. On the one extreme were some very close to the lay-person, and others near to, or experts transferring to, new expertise and in between. Some, particularly at the post-graduate level (though not exclusively), were also in practice at the same time as studying. Some were pursuing specialism as a change or to open up career directions. This was particularly the case for urban design students, which included a significant change in skill set requirements, from planning (largely written, discursive) to urban design (visual, formal).

Unlike some other research events, student involvement was not situated consistently in real-world practice processes.

The main research activities which involved students were situated within a process (module) that was closer to practice than many more theoretically driven learning experiences. Each project is connected to an established collaborative, real-client, real-world brief. The primary event relates to a module entitled 'CoLAB' (Collaborative Laboratory). This runs yearly at the Birmingham School of Architecture and Design as a selective option. Students chose and self-enrolled in these modules. The researcher-participant aspect was stated before the choice was made. The students who chose this option were from a range of discipline studies, namely undergraduate (UK Level 5/year 2): BA Architecture, BA Landscape Architecture, BA Interior Design, BA Video Games Design and Development, and Post-graduate (UK Level 7) MA Architecture, BA Landscape Architecture, and MA Urban Design.

Public and Mixed Background

Although the previous pages have given an account of various participant categories, it was the case that many of those involved in this study (including myself) did not fall strictly into one category but might fall into several of these descriptions. The public, being the most diverse category in theory, but in the case of research events, they related to specific places, as residents or visitors.

Researcher-as-participant

The researcher's ('my') role as a participant was considered as part of the participant base, with longitudinal influence across multiple comparative events (contexts), as part of a focus on a context-mechanism-outcome ('CMO'). This influence was acknowledged from the outset to participants and had the deliberate intention of exploring and testing the extent of causal powers (Ackroyd and Karlsson, 2014, p. 8). With this approach, my influence was considered as an agent for promoting action, reflection, and potentially encouraging other participants to explore change. In an action research approach, my own knowledge base and experiences shifted, as with other participants. For example, in the use of spatial computing, my experiences were also often entirely new or advanced, as they were to other participants.

The approach of 'researcher-participant' input is considered useful, for providing *"an appreciation for mutuality, reflexivity, co-construction, and respect for both the knowledge and vulnerability of interviewees that cannot be learned simply by reading about it"* (Probst, 2016). This forms a process towards best interpretation of the reality of the situation by considering multiple views (triangulating) (Creswell, 2013, p. 251), which is subject to individual, subjective perspectives. This also aligns with the research topics of spatial computing, Co-Urban Design, where the dynamic contextual conditions of each case study influence the nature of collaboration and transdisciplinary subject aims. In all cases, researcher input is acknowledged and evaluated comparatively as part of attempts to better understand aspects such as influence from social power relationships, preconceptions, and personal biases.

In moving beyond positivist 'unnatural' attempts at being an objective observer, there was no attempt to separate myself from influence. Broadly, this took a critical realist (aligning to wider post-positivist) view that:

a) An individual researcher cannot see or measure a truly objective reality, but parts of a 'stratified' one (ontology focus). This aims to allow understanding of the underlying structure and systems that might have influenced the data beyond the empirical surface reality, i.e. seeking to explain the physical and social systems, that might influence what can been seen, heard from participants.
   i) And study of 'real-world' situations involves roles and knowledge embedded into the reality itself, as contextual conditions, embedded practices.
b) That, in attempts to understand underlying structural causes; via looking at effects; any attempts at removal, or avoidance of influence (bias, power), the researcher's own, or otherwise, might create a artificial context and a missed data contribution, obscuring ability to explore and understand real-world contexts (Critical Realist: underlying 'structure'). As a practitioner (designer) and lecturer (academic), also reflecting on practice and collaboration (McNiff, 2017, p. 41).

As such my influences are critiqued and placed in context via triangulated evaluation. This includes minor and/or or major influences (biased, or contributed), causing and effect of changes in behaviour of other participants and my own–also, as is 'normal' in the roles I perform, as aligning to ideas of the reflective practitioner (Studies and Competition, 1998; Mccarthy, 2011). I was careful, and increasingly so throughout the timeline of the project, to try to let others talk more, though often, especially when students and public participants were involved, there was a need to push conversation, both generally to encourage engagement and particularly to encourage deeper degrees of reflection with relation to the research question.

Also, in the evaluation, care was taken not to consider my influence, as being the sole direct evidence in and of itself, without interaction or triangulation to data from other participants. In addition, my involvement as such, its limitations, and influence were specific where appropriate, freely acknowledged, and discussed with the participants. In all, this aspect of data via researcher as participant contributes as part of a narrative contribution to a conceptual inference to the reality of the situation, rather than as claim to pure positivist 'evidence'. In student engaged events, the broad roles of 'student', academic ('lecturer'), stakeholder ('client', project lead), were present and significant throughout. This was clear from the style, depth, and tone of communications. In the early stages, I intended my role to be 'PhD student' (independent interest in spatial computing), which was stated and restated. I was repeatedly asked questions by the students on assessment and design decision aspects. In my own mind, it was also very difficult to break from my pre-existing and wider roles. This is not simply a question of role, but the broad difference in experience and knowledge that one might expect between students and academics, as well as specific experience and knowledge differences between individuals. Incorporate elements of spatial computing often rely on the primary researcher as a specialist, both to instigate thinking about concepts and ideas to explore and to facilitate and navigate technical capabilities and issues.

Participant list – reference

TABLE 10 - PARTICIPANT TYPES AND REFERENCE CODES USED IN RESULTS CHAPTER

Code	*Projects, Events*	*Year*	*Discipline, Specialisms*	*If named*
Academic				
AC-a	Live Event_BALA, DM	2022	Design Management	
AC-b	Live Event_CoLAB23	2023	Architecture, Immersive Technology	Harry Conway
AC-c	Live Event_CoLAB22/23, RSS	2022-24	Architecture, Urban Design	
AC-e	Interview - BCU	2023	Visual Communication	
AC-f	Interview - BCU	2023	Landscape Architecture	
Practice				
PR-a	Interview - Choral	2021	Architecture, Urban Design	Andrew Hilton
PR-b	Interview - Choral	2021	Architecture, Urban Design	Prof. Mohsen Aboutorabi
PR-c	Interview - Unity	2021	Spatial technology, Architect	
PR-d	Focus Group - BCC, Live Event - RSX	2022	Architecture, Planning	
PR-e	Focus Group - BCC	2022	Planner, Spatial technology	
PR-f	Focus Group - BCC	2022	Planner	
PR-g	Focus Group - BCC	2022	Planner	
PR-h	Focus Group - BCC	2022	Planner, Spatial technology	
PR-i	Interview-WSP, CoLAB_22	2022	Urban Design, Landscape Architecture	Paj Valley
PR-j	Focus Group - Define	2022-23	Landscape Architect	Megan Lloyd
PR-k	Focus Group - Define	2022-23	Landscape Architect	
PR-l	Focus Group - Define	2022-23	Architect, Urban Designer	Feba Abraham
PR-m	Focus Group - Define	2022-23	Landscape Architect	Sophia Brown
PR-n	Focus Group - Define	2022-23	Landscape Architect	Helen Young
PR-o	Focus Group - Define	2022-23	Landscape Architect	Harry Powsland
PR-p	Focus Group - Define	2022-23	Landscape Architect	
PR-q	Focus Group - Define	2022-23	Planner	Kirstie Clifton
PR-r	Focus Group - Define	2022-23	Architect, Urban Designer	
PR-s	Focus Group - Define	2022-23	Landscape Architect	
PR-t	Focus Group - Define	2022-23	Urban Designer	
PR-u	Focus Group - Define	2022-23	Urban Designer	
PR-v	Interview - Arkio	2022	Architecture, Spatial technology	Johan Hanegraaf
PR-w	Interview - Define	2022-23	Urban Design, Planning	
Public				
PU-a	Live Event_CoLAB23	2022	Group – unknown background	
PU-b	Live Event_CoLAB23	2022	Group – unknown background	
PU-c	Live Event_CoLAB23	2022	Group – unknown background	
PU-d	Live Event_RSX	2022	Group – unknown background	
PU-e	Live Event_RSX	2022	Group – unknown background	
PU-f	Live Event_RSX	2022	Transport and Logistics Engineer, Manager	
PU-g	Live Event_RSX	2022	PhD Business/Design	

PU-h	Live Event_RSX	2022	Designer	
Students				
S-a	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-b	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-c	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-d	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-e	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-f	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-g	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-h	Live Event_BALA, DM	2022	UG Landscape Architecture	
S-i	Live Event_CoLAB22	2022	UG Architecture	
S-j	Live Event_CoLAB22 - G1	2022	UG Architecture	
S-k	Live Event_CoLAB22 - G1	2022	UG Architecture	
S-l	Live Event_CoLAB22 - G1	2022	UG Architecture	
S-m	Live Event_CoLAB22 - G1	2022	PG Landscape Architecture	
S-n	Live Event_CoLAB22 - G1	2022	PG Architecture	
S-o	Live Event_CoLAB22 - G2	2022	UG Landscape Architecture	
S-p	Live Event_CoLAB22 - G2	2022	UG Architecture	
S-q	Live Event_CoLAB22 - G2	2022	PG Landscape Architecture	
S-r	Live Event_CoLAB22 - G2	2022	PG Architecture	
S-s	Live Event_CoLAB23 - G1	2022	PG Urban Design	
S-t	Live Event_CoLAB23 - G2	2022	PG Urban Design	
S-u	Live Event_MALA	2022	PG Landscape Architecture	
S-v	Live Event_MALA	2022	PG Landscape Architecture	
S-w	Live Event_MALA	2022	PG Landscape Architecture	
S-x	Live Event_CoLAB23 - G1	2023	PG Landscape Architecture	
S-y	Live Event_CoLAB23 - G1	2023	UG Interior Design	
S-z	Live Event_CoLAB23 - G1	2023	PG Architecture	
S-aa	Live Event_CoLAB23 - G1	2023	UG Design Future Living	
S-bb	Live Event_CoLAB23 - G2	2023	UG Architecture	
S-cc	Live Event_CoLAB23 - G2	2023	UG Architecture	
S-dd	Live Event_CoLAB23 - G2	2023	UG Interior Design	
S-ee	Live Event_CoLAB23 - G3	2023	UG Design Future Living	
S-ff	Live Event_CoLAB23 - G3	2023	PG Architecture	
S-gg	Live Event_CoLAB23 - G3	2023	UG Architecture	
S-hh	Live Event_CoLAB23 - G3	2023	UG Interior Design	
S-ii	Live Event_CoLAB23 - G3	2023	UG Interior Design	
S-jj	Live Event_CoLAB23 - G3	2023	UG Product Design	
S-kk	Live Event_CoLAB23 - G3	2023	UG Architecture	
S-ll	Live Event_CoLAB23 - G3	2023	UG Architecture	

4.5 Data Formats

Data were captured using a range of methods, though some data formats contributed to a significantly higher amount of data, as table 9 and expanded to follow.

TABLE 11 - METHODS WITH RELATION TO FORMAT

<table>
<tr><th colspan="2">Method</th><th>Data Format</th><th>Quantity</th></tr>
<tr><td colspan="2">Interview / Focus group</td><td rowspan="2">Audio, video files + transcript, researcher notes (text)</td><td rowspan="2">Extensive, majority of data</td></tr>
<tr><td rowspan="4">Events</td><td>Audio-Visual Recordings</td></tr>
<tr><td>Visual Analysis Design outputs</td><td>2D/3D graphics, hand-drawings, diagrams photos– and/or as mixed portfolio (images)</td><td>Supporting, from extended cases only (live events)</td></tr>
<tr><td>Observation Design activities</td><td>Video recording (audio-visual), photographic/ screen capture (images) + transcription, researchers observational notes (text)</td><td rowspan="2">Supporting for reflection, starting point for abductive inference</td></tr>
<tr><td>Surveys</td><td>Online form (text, spreadsheet)</td></tr>
</table>

Audio and Video recording

Where feasible, event and subsequent activities were recorded using audio or video (& audio). This captured overall discussion, and where relevant spatial behaviour within the activities, the most pertinent was capture from headsets (e.g. undertaking collaborative design actions). Audio-visual data were either live captured in-situ with activities, and/or as a reflection-on specific activity and/or the whole project broadly. Due to the nature of live recording in large/exterior spaces, audio needed to be edited using compression and loudness normalisation to enable more audible data. This used the following equipment:

- Audio: captured using Google Recorder app with a mobile phone for interviews, live/immediate transcription feature, plus plug handheld, microphone for external environments and holding near to participants. Audacity for audio processing when necessary.
- Video, screen capture recording, online or live in-situ.
    - From VR Headsets: Rift S / Quest 1/ Quest 2 – transcription post capture Google transcription services.
    - PC, with Microsoft Teams video call recorder with in-built transcription by Microsoft (which was more accurate than Google)

Transcription was largely achieved using automated services built into varied due to environmental acoustic conditions (e.g. outside vs inside, closed room vs open-plan studio), as well as by social context, including the number of concurrent people concurrently talking, creating background noise. In most cases it was not possible to mitigate this greatly without damaging the social conditions also required for event success (stopping groups talking), due to the nature of the live events and limitations to equipment and support. These issues were often compounded by additional complications of SC technologies and the live nature of the project, proximity of microphones to dispersed groups, varying participant volume and the setting up of multiple positions for recording. This was an area improved as the research continued, aiding in better capture as the research progressed.

Whilst interviews were captured in full, the less controlled, conversational and in more challenging acoustic environments, audio-visual data was analysed to appreciate the important sentiment and intent of participant meaning at that moment (as naturalism vs. de-naturalism (Oliver, Serovich and Mason, 2005)). As such, the analysis of data followed stages of researcher analysis, firstly outline tidying up, getting overall sense. Secondary, adding detail, any missed point, or overlooked perspectives (such as contextual interpretations). Some data sets were reviewed in many stages, towards the final data set (see appendix).

In summary, analytical clarification of transcriptions focused on those comments considered important only, though this included some instances where it felt appropriate to convey emotional or contextual understanding, inflections, pauses, etc. which might indicate more subtle emotional responses. Some observational, reflective, or aligned informational elements were added in brackets '[]' at this stage of review. The process followed: listening through the audio/video, making analytic notes, and only correcting the transcript where the content was felt to be worthwhile. Examples are available in the Appendix.

Text notes/Photographs: observations and reflections

Notes were taken on observational and reflective points at, or soon after the live events. These became an increasing element of valuable data, providing context to participant responses and deepening the interpretation. The notes followed key types of record, appropriate for different contexts within which data was collected:

1) Technical, or system setup conditions, issues
2) Participant involvement, movement, and actions: *level* and *type* of, for example:
    i) Engagement level, type
    ii) Activity or use, problematic uses
    iii) Design approach, e.g. supported creativity, pragmatism, speed/efficiency

Emotional response, e.g. appeared to be 'happy', 'excited, 'frustrated'

4.6 Analysis and Evaluation

Grounding and Coding Qualitative Data

Due to the emergent nature of spatial computing as a research topic, the research aimed to derive its evaluations from the research data collected (rather than testing a hypothesis). It broadly followed the principles of 'constant comparison' as presented by Grounded Theory (GT) (Strauss and Corbin, 1991). The original grounded theory (strictly) dictates an objective approach to grounding all evaluations from data. However, the critical realist philosophical position taken here, views such a search for absolute objectivity as an impossible paradox: a researcher, as an experienced adult, cannot start with a blank slate of knowledge, nor could an innocent infant have any idea of what to do, or why (Haig, 2010).

In addition, a false objectivity might miss out on potentially valuable perspectives (Braun and Clarke, 2022). Hence, the GT approach used here was less strictly applied, but took a more emergent approach, as described by Assemblage theory (DeLanda, 2016), acknowledging that the researcher is also only one lens of many that should be considered (Bhaskar, 2008). This is discussed further in section 4.3 as 'researcher as participant'. Hence, the thematic coding and relationship analysis used here aligns with contemporary revisions to GT, which give appreciation to the paradox as mentioned (Charmaz, 2001; Timonen, Foley and Conlon, 2018). The coding approach relates to the core research questions, which fit within critical realist aims for evaluating empirical data – specifically, from the perceptions and actions of users. This is interpreted within context and with the aim of pointing to likely underlying (causal) mechanisms (Archer *et al.*, 1999).

Evaluating Assemblage, Critical Realism, Affordances

The philosophical basis of data evaluation takes a critical realist basis. Primarily this is to look not only at how and what effects have occurred, but in the less established context of SC technology (emergent (DeLanda, 2019)), to start to shed light on why they might have occurred. In this study, data from multiple actions and perspectives were collected to seek explanation for why certain effects were caused: where reality is hidden behind highly complex' layers of influence (stratification) that we do not know, or cannot fully see (Bhaskar, 2008). The approach searched for 'best approximation', by considering a wide range of data types and formats, and using stages of reasoning, aligned to repeating, continual processes, towards ever increasing understanding of why things might happen (Archer et al., 1999).

> *A "non-empiricist, stratified, and relational ontology", the key concept of emergence, as "engagement with the (social and non-social) world", "between human beings and the various orders of natural reality" Maccarini and Prandini, in (Archer, 2009)*

Though supporting the aims of CR, Raduescu and Vessey (2008) argue that methods for critical realist research are often too diverse, context specific, and inconsistent with each other, presenting a highly confusing position for developing research methods. Following this, they propose that methods need to adapt to the level of prior theory, suggesting that lesser-known areas need to follow an exploratory approach. They argue that it should align with grounded theory methods, that are not hypothesis-driven, but have theory emerging from data (being 'grounded').

Moving on from this earlier critique, the evaluation approach used in this study followed that of Wiltshire and Ronkainen (2021) who describe their method for CR evaluation as delving into CR's three levels of reality, where likely causal mechanisms are sought via stages of qualitative thematic analysis (Braun and Clarke, 2022), with each level having increasing inference:

1. (Empirical) Experience - participants subjective statements: "intentions, hopes, concerns, beliefs, and feelings"
2. (Actual) Inference – interpreting broader meaning as a conceptual redescription, i.e. collated from different participants into themes
3. (Real) Disposition – relating themes to theory on potential plausible underlying mechanisms: as 'powers & liabilities' (Zachariadis, Scott and Barrett, 2013)

> *"The transition from (ii) to (iii) typically occurs when a realist interpretation of the mechanism posited in the model becomes acceptable." (Bhaskar, 2008), e.g. iii. is iterative, an ongoing 'current best-guess'*

As CR seeks best explanation or approximation of plausible theory (Ackroyd and Karlsson, 2014), triangulation across datasets was used to try to uncover potential relationships, between a cause and effect: 'mechanisms' (or, causal mechanisms). This was an iterative process, builds and develops across different data sets using abductive and/or retroductive reasoning to refine and sculpt causal explanations, of why certain effects are likely to have been caused.

> *"researchers are likely to be well versed in critical realist tendencies towards complexity, context, open systems and the necessity to theorise beyond empirical observations" (Wiltshire, 2018).*

Here, this related to two established types of inference (Cramer-Petersen, Christensen and Ahmed-Kristensen, 2019; Mukumbang, 2021):

- Abductive – observation to 'likely' explanation via interpretation in context (creative)
- Retroductive, combination of C with A-B information. Process seeking explanation, looking for Causes – refined by further testing of initial conjecture

As Alvesson and Sköldberg (2009, pp. 5–7) argue, applying purely inductive or deductive approaches can too closely constrain the research process. An abductive approach allowed a more reflective evaluation of the empirical data considering theory, and the theory considering empirical data. Though this presented a less certain initial position, the use of a systematic reflexive process allowed for interpretation that was evaluated more holistically, and from a range of perspectives and levels. This lead to open approaches that increasingly focused on and refined the most appropriate methods with the reduction or removal of those less useful (Ackroyd and Karlsson, 2014).

Reoccurring themes were assessed iteratively and with increasing depth of abductive reasoning (Belfrage and Hauf, 2017) with reflexivity (Alvesson and Sköldberg, 2009; Archer, 2009) which south to understand the data in context (/retroduction).

FIGURE 22 - EXAMPLE DATA ANALYSIS (SEE APPENDIX) – EVALUATION, DEEPENING INTERPRETATION

Participant data ***Empirical***	**Summary /** **Code**	**Context and Interpretation** (simplify discussion) **Actual**	**Evaluation aspects** (AND refer knowledge, lit) **Capacities** (person), **Affordances** (system) - **Co.Mechanisms** (social and physical) **[possible why?]**	**Reflection - 3. considerations SC-CO.UD** Gaps, Limits, Further Research
names due to set up (not personal devices), no time to set up avatars too faffy. *Having to discuss who the avatar is.* *'NAME' is not 'Kevin'.* *trees locked to origin, not editable - as previous problem* *Seems frustrated -*	identity - non-identifiable	Alignment of identity to avatar character was not possible.	Did not afford quick communication, caused confusion. The technological setup obscured who was who. Does not allow quick setup, users did not have perosnal devices/accounts prepared.	The setup of headsets as individual basis, does not easily allow multi-user, or switching of users. If everyone had a device to use, less of an issue.

Critical Thematic Analysis

Primary data (collected) and secondary data (literature) were qualitatively 'coded', by extracting qualitative datasets and giving them a description (written tag, explanation), using text description. The primary and secondary data sets were coded in entirely separate processes and later compared for consistency, to assess for potential gaps and the weighting/significance of those gaps.

Over time, the initial draft codes are conceptually refined, eventually collated, combined: otherwise built towards, key themes. These were edited within more simplified grouping by titles and tagged with visual colour reference. These themes and sometimes sub-themes were used to present the data in the Discussion, with alignment to the research objectives and questions [see – chapter 6].

The method of coding followed two types of codes. Firstly, the creation of detailed codes of a very specific descriptive nature. As the process continued, these were combined to form broader codes, which were increasingly brought together to form key themes. As the research progressed, these built clarity and consensus across the diverse data sets (Braun and Clarke, 2006, 2022).

From the critical realist perspective however, this point is considered an insufficient conclusion. Therefore, the final stage of evaluation attempted to get underneath the surface of these codes, that is, not simply to provide them as a description at face value, but to infer meaning through the overall comparison and holistic evaluation. This last stage considered the broad themes relating to critical realist levels 'Empirical, Actual, Real'. Whilst the data itself was empirical (observed), it was understood within its context, inferring deeper meaning (actual), and aiming to shed light on possible 'Real (mechanisms: powers, limitations, etc. See chapter 2.3). Broadly, the intent was not to take the data at face value, but to ask, why, what might it mean, beyond a literal statement. The discussion leads to best estimate of possible underlying causal mechanisms from the data collected (Wiltshire and Ronkainen, 2021).

TABLE 12 – EXAMPLE PARTICIPANT DATA AND INTERPRETATION FROM 5.6 SEE FULL DATA IN APPENDIX

Type	*Participant data*	Open code, context analysis
Student Public	*showing the 3D model gate they had made, using AR* *'No gate, of course not! If you have a gate, it becomes a Ghetto'. Very ugly!*	Student had finished proposal before asking people what wanted. They had not yet considered the potential diversity of social-political views in their design.
Researcher Public	*Showing AR walk (Augment), demoing basics. Using phone to place objects as instructed by public* *So I can choose? I use my phone and then save it as a picture..* *That's interesting.*	There was a difference in how each saw the usefulness of the AR app at this point.
Public	*"Is it possible to make the people moving?"*	Simulating, enhancing, life of the place

Social Context of Data Types: Situation and Influence

The following table (11) defines the core data types and their likely social influences. Understanding the broad social context of the data collected allows for greater contextual understanding of how the approach, answers, and physical actions relate to specific research outcomes and limitations. As part of a reflexive methodology, this also considers the researcher's influence, experience and thoughts as fundamentally inseparable and also, equally useful, data (Braun and Clarke, 2022), [see subchapter 1.6 – Researcher as Participant.

TABLE 13 - DATA TYPES AND LIKELY SOCIAL INFLUENCES

Situation	Likely Influences	Helps to understand
Live Event/Action, As simultaneous or very recent. - reaction to direct experience, or observer/social interaction with direct experience	Not preplanned, reaction, in speech or physical actions Instinctual reactive, emotional. More colloquial, less refined / less considered	Emergent, raw thoughts, ideas at conception
Focus groups Staged, relatively formal. Participants react to specific questions, prompts as previous non-focus group shared experience (prior event)	Social structures and power dynamic, peer-pressure, hierarchy-status, expected conventions. Steer by content of questions, way asked, time to consider	Direct response to key questions emerging from research. Level of understanding, depth Pre-conceptions
Situational Conversation Less rules/prescribed context: exploratory, fluid, more ad-hoc discussion - in and out of relevance: e.g. 'Design Studio'	Highly influenced by others adjacent, social confidence, hierarchy within social group. Often highly personalised, colloquial	Developmental, emergent thoughts Thoughts from less socially integrated people (less confident of situation)
Interview broad, loose questions reactive, exploratory questions from researcher - fluid	Desire to present professional, personal 'appearance': knowledge and skills, relative to personal perception of peer/practice, to title (e.g. discipline or status). Financial motivation, short- or long-term approach.	Direct response to key questions emerging from research Deeper, reflection on experience
Researcher notes: On experiences within events, of interviewing. Researcher first hand exploration with spatial computing technologies. On previous and current industry and academic practice	Navigating complexity of issues, uncertainty. Testing, critiquing knowledge basis, pre-conceptions, influence of decisions and research design choices	Reflexive analysis of embedded research experience, the lens that ties together all the data Being up to date on technological capabilities, limitations, access

4.7 Ethical Considerations

Data Management

Aligning to the University of Sheffield policy, participants' data remained anonymous unless they specifically stated that they wanted to be named. Where anonymous, there is no way to connect with an identifiable individual. Access to the research data was only made available by the primary researcher Lucas Hughes and the supervisory team: Dr Kevin Thwaites, Dr James Simpson and Dr Bobby Nisha. Any technological platform used was reviewed to ensure that the data security was compliant with the international information security management system. All data collected were stored and analysed on a secure server. The anonymised pooled data may be made available for future research purposes, following further security checking at the end of the project.

Ethical Review and Approval

The research methods used were granted ethical approval by the University of Sheffield Ethical Review Panel for working with students and subsequently, for working with professionals and the public. As such, the content is greatly summarised here, with a focus on the methodological implications.

The ethical review considered site conditions as physical and cultural contexts, including potential navigating of power structures and differences, namely on the ethics of collaboration and participation. The main rationale for all ethical decisions was to build trust and encourage open dialogue.

- Research aims were made clear to participants in advance
- Conflicts of interest were reduced: the researcher (also a tutor) was not involved in assessment of student outputs related to the student-based research projects
- Consent was gained by forms and statements: Making participants aware of what is being consented to. Clearly stating/agreeing policies, and that data would be anonymous unless requested otherwise. This included the level of consent for various activity types to allow options relating to diverse backgrounds.
- The overall nature aims, methods, and results/arguments were opened for discussion throughout, supporting the exploratory nature of the study.
- No payments were offered for participation

Key ethical considerations for all participants

Psychological harm/distress was expected to be minimal due to the nature of live design activities, for which various aspects were considered. The main approach was setup with alignment to professional systems and procedures relating to the events held at or with relation to Birmingham City University (BCU).

Otherwise involved:

- Through discussion in a 'live' context, mitigated potentially sensitive nature of topics
- monitor and resolve conflict –
- monitoring VR use on the experience of exiting VR short-term confusion
- Technical and cognitive introductions to equipment, build-up of tasks, allowing time to settle in.
    - setup of systems, spaces, including social arrangement to avoid physical harm
    - cleaning equipment (particularly during Covid19)
- Having a 'Designated Safeguarding Contact'
- asked participants to Self-identify prior, or issues arising for potential alignment to established support services
- Recruitment of Participants with relationships to established professional networks of the researcher, by open invitation to be part of the research, and/or optional selection to join academic activities where research was made clear prior to signing up with relation to the research/data collection. Academic judgement of participants by the research was avoided for the specific research activities.
- A short summary of the scope and aims was provided before each event, including a consent form (digital) for signed return, including options, in some cases (other academics) by word-of-mouth agreement as part of the audio recording. Access was given to a participant information sheet (appended): aim, conditions
- On-site activities involved a risk assessment to be completed, which supported a deeper consideration of the site and group setup.
- Specific additional setup: the public event involved an on-site security presence provided by the Southside Business Improvement District. The Arkio collaborative design sessions were supported in setup and introduction by the on-site technical manager and supporting staff.

Looking at causal relationships between perceptions and actions promoted a need to seek broad appreciation from diverse participants. The variability was not monitored quantitatively in the research but was broadly noted as diverse in demographics as institution publication (*Transparency information*, 2024).

- case studies events were of broad, multi-perspective, multicultural interest
- presentations promote via inclusive content

- The focus is not on technical/technology, which can influence male bias, but on urban design and collaborative processes.
- Sign up was not controlled by background, through the case study context may naturally align to professional, as well as stakeholder-interest in areas of Urban Design: as a transdisciplinary spectrum connecting Architecture, Landscape Architecture, Planning, Design Management, Geography, Social Science and related areas.

4.8 Dissemination and Reflection

Visual slideshow presentations were used to introduce and aid participant group familiarity with key topics, terminology, examples of technologies and applications, for which the participants varied in their prior knowledge, exposure or familiarity. This approach also enabled more immediate participant feedback, in reaction to seeing potential application in their areas of expertise or life experience, as well as on the developing ideas of the researcher. These presentations were not directly used for primary data collection, but to support broader development of the key theoretical understanding and to aid assessment and reflection on the general engagement, understanding and value. A highly audio-visual approach using sections of videos and combinations of images to try to convey the immersive nature of spatial computing (though the actual experience was not replicable on a 2D screen).

The content was designed to be neither promotional, nor overly critical of the research topics, but to present balanced information, as derived from existing knowledge presented in the literature (Chapter 3). It included in presentations was improved through the timeline of the research, and to adapted to the event context, and specific audience. For example, for practice focused interviews, the discussion of research method and more explorational aspects were reduced, for focus on practice applications (e.g. at construction week, practice focus groups). This considered the following structure:

1. Introduction – overview of themes, terms Urban Design, Collaboration,
2. Collaboration and Participation, including discussion of example case study (as discussed researcher reflection on practice – see 1.6)
3. Spatial computing types and potential

Presentations helped to test and focus the attention of the researcher in a reflective way. This allowed feedback on developing ideas. Reflection on participant interaction tested the clarity of the researchers personal understanding and coherence of ideas being considered. A final version of the presentation with summary of key findings, is now being used by the researcher for local dissemination of the research findings, to academic and practice colleagues.

Key presentation activities:

- Construction Week (2020): Live, on-stage presentation to practice observers. A small but engaged public audience: approximately 20 people stayed for 20 minutes, with a further 10 minutes of follow up question-discussion points. Interest from the audience was especially on impact on early stages of collaboration.
- EURAU (2021) to other academics in person and teams. Participant questions related to the nature of visual communication.
- Similarly, within the following data collection events:
    - Birmingham City Council – as prompt/for reflection
    - Define Limited – as prompt/for reflection
    - To students/partner stakeholders within the 'CoLab' (collaborative laboratory) academic modules – as a means of introduction to the longer-term projects

5 RESULTS

The following chapter presents an overview of data collected through a series of research events, for which each event is understood as providing critical contextual understanding of participants' perceptions based on reflective data, understanding of intentional meaning, needs context of social, group context for understanding, nuance, reaction to others, level of certainty, etc.

In summary, the analysis has a focus on the key points of most value to research aims, identified from a larger data set (see appendix for deeper examples). Data have been broadly categorised within the narrative to appreciate context and meaning. As required for clarity, some data are presented in a paraphrased, contextualised, and interpreted format, while retaining the original meaning.

The sub chapters each integrated data from chapters: 5.1 expert reflections (Interviews/focus groups), 5.2 technical testing activities 5.3 combined pilot testing and then each longer event. The actual timeline of events was often overlapping, as shown in the Methodology (see 4.1).

Each sub-chapter starts with an introduction to the context of data collection, as:

- Relevant background to interviews with key stakeholders, such as their role and experience beyond the project
- Context of case studies – with each being a separate, live-action design project, such as conditions, collaborator mix

5.1 Interviews/Focus Groups

The following section summarises accounts of discussion with a range of practising designers, planners, academics, as well as software developers working in collaborative spatial computing applications.

Practice Choral Studio – Urban Design Practice

> *"just pop him into Google Earth and he understands it all of a sudden…that's saved me three days' worth of trying to explain a project"*

In November 2021, the researcher met in-person with Choral Studio at their Birmingham, UK office, which collaborates with another office in Chengdu, China. Their portfolio of work spans Urban Design, Architecture, and Landscape Architecture, with a distinct focus on Chinese-located projects. The directors, Andrew Hilton and Mohsen Aboutarabi are the main participants in this interview (See 4.4, Table 8, PR-a and PR-b as named participants) and were also joined by a lecturer in Architecture (AC-c, also a participant in later events, Colab 2022 and 2023, and Reimagining Southside).

Both Andrew and Mohsen also have a background in academia: Mohsen is an Emeritus Professor of Architecture at Birmingham City University, and still an active researcher. Both were known to me prior and specifically selected because of their known alignment and unique experience related to the subject themes. I have worked with Andrew and Mohsen in practice (as a consultant) and collaborated on several academic activities, including in a previous 'CoLAB' at BCU, which explored conceptual themes and the technical setup of spatial computing within an urban design context (see 1.6 reflection on background experience: Hybrid Realities).

Prior to this interview, I was aware of and had conversationally discussed their practice exploration and application of SC and expected they would have specific, somewhat uncommon practice insight, and specifically in applying SC in certain workflows. Within this context, the interview approach was free-flowing and led predominantly by the participants with some proactive and reactive questions.

FIGURE 23 - CONCEPTUAL IMAGES (CHORAL STUDIO)

Design Communication

Their design process moves from hand drawing, diagramming, and Co.VR:

> Andrew *"…most of our projects begin with a discussion of a diagram. We do a lot of hand drawing work and then we have this <u>other extreme</u> now, where we've got VR".*

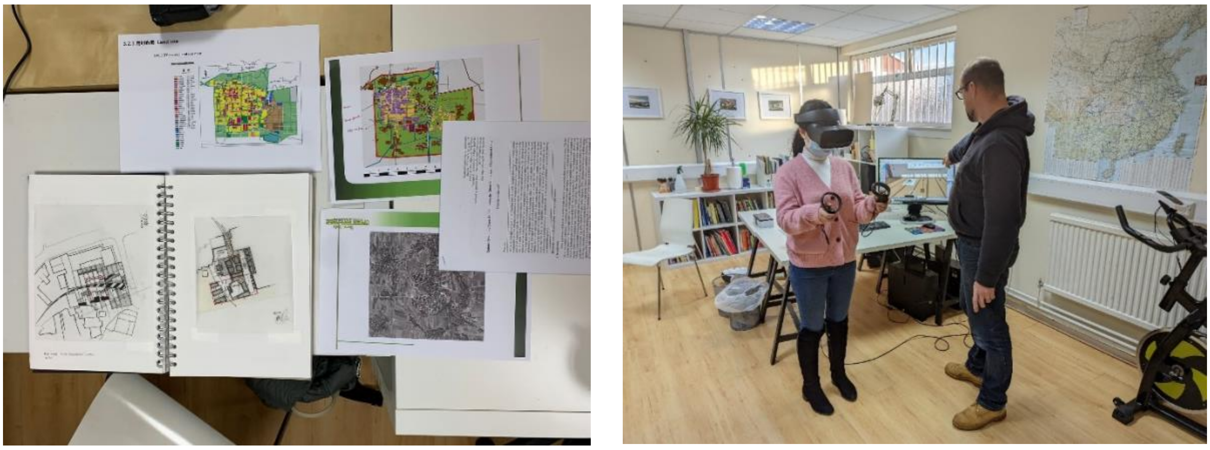


FIGURE 24 – DIAGRAMMING, SKETCHING AND 3D VR

Choral studio mainly uses VR within the early design process as a form of real-time digital construction. For them, it allows remote members of the team to all join within the design and to discuss and edit it in shared real time.

> Andrew: *"it might even be better than being there, because you can sort of zoom out, understand where certain topographies are, and then drop in again, and look at something up. It all depends on the quality of the data. But it helps us understand the place much faster than if we were trying to trawl through a cad drawing that's got contours on it."*

Andrew suggests that all design communication processes are various translations of ideas, from the first idea in your head, to working drawings, to bill of quantities, to construction on site. For Choral, there are additional translations between the languages of the two offices (Chinese and English), so they rely particularly on drawing to translate design ideas:

In nonverbal communication, *"Drawing is amazing at doing that. I think that VR has the potential to come close to that more so than computing screens. There's something bodily about it, which is different"*

Using VR Sketch (*VR Sketch*, 2024), with a simple 'tic-tac' avatar Andrew states that it is the tactile immersive design process and being able to hear, talk and draw in this shared space. It was felt that VR developers' current areas of focus are not key elements that make a difference to the design process. For example, the ability to see each other's rendered face (avatar) is not a critical priority.

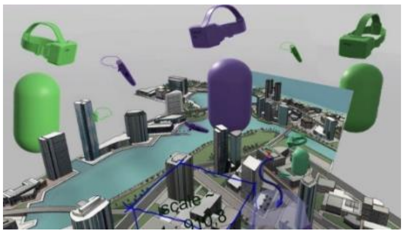


FIGURE 25 - VR SKETCH

The social-physical performance of design

Andrew - Behind the screen, *"your filtered, you have understood the world. It's constrained view and your interface with that is through another device: a mouse, keyboard, or something. And it's another step away from the relationship of your tactile body and what you're actually doing."*

He recalls his experiences in practice before digital tools took over, and feels that these spatial technologies, are getting back to that prior, more physical experience of design working. *"Looking across a room with everybody stood up, moving around and people coming and standing next to the board that you're on, having meetings around the board... And that there's something social about that. I think that the Sketchup thing (VR plugin) starts to get back to that."*

He argues that this social and physical performance is an important aspect for making a good design. Screens and other abstract experiences remove interpersonal relationships between people.

He felt that with VR *"there's something about being present, standing up and working, a line on the ground".. "Drawing with somebody else, there's a sort of bodily relationship between you and what you're producing". "I can draw", "I have to have to bend down to grab a surface and then extrude the thing". I can stand back and say behind, I am this high.. 'I can see the hills in the background, and I want to do something with the skyline, that's sweeps, and I can sit and go down different streets and, and literally massage the thing"* (*/sculpt). *I ask if this is like a real construction. "Yeah, exactly. There is something about it (VR), which is radically different that I do not understand. I do not know, if it's made me a better designer, but it's brought me closer to a better understanding."*

He compares this to hand drawing, as a "closer relationship with design, than you could have in any other format", where *hand drawing but instinctive but chaotic, whereas VR is not chaotic, "what you've designed is more considered and more careful than if I was just sort of swooshing stuff around when drawing".*

It was felt that there is something about the approach in Sketchup VR which is more technically considered than other VR software, such as Gravity Sketch or Open Brush.

The Power of Experience in Reviewing Place and Design Ideas

Although not a frequent gamer, Andy recalled his interaction with the VR game Half Life Alyx (*Half-Life: Alyx*, 2020), where he had an emotive reaction and shift in thinking following an immersive experience in an environment. He was already familiar with the following:

> *"I immediately saw Lebbeus Woods' Morphosis; Coop Himmelblau, that sort of 80s-90s deconstruction, which I was obsessed with, It was the thing when you were at university.. The Bartlett drawings, they are still doing that... I remember going... Yes, it is amazing, but it is also fucking terrifying! The scale, of it. It is grotesque! It is alien! and it is unpleasant!*
>
> *Architects need to be really, really careful because the stuff that they aspire to, they see all this imagery, try to... do! repeat it in student projects, but they go out into the world, myself included, hoping to one day produce something that looks like that.*
>
> *And I came out thinking, I do not!' want to produce anything that looks like that..."*

Mohsen places this meaning in wider context, arguing that the nature of culture is intangible and difficult to understand through sight alone. In real life, he states, "the most important thing is its cultural dimension. That is why, when they ask you to design a city in Saudi Arabia, it is different from designing a city in America. The cultural aspect and people's behaviour, you cannot just see (this)."

In the future of SC, Andrew sees that the integration of certain tools, will be critical to incorporate the reality of a place and project in a deeper way:

> *"The next stage is about combining…if we can get GIS in there and it'd be as interactive and immersive as 3d Sketchup, so you can move layers around and drop them in and actually interact with it…that that's a game changer"*

Practice – Define. Planning and Design

An interview with one participant (*PR-w*) took place in September 2022 & and two Focus Group in September 2023. Define is a practice specialising in Planning, Urban Design, and Landscape Architecture, *"with a dynamic and collaborative approach"* (*Define*, 2024). They also have specific areas of interest in spatial computing and incorporate regular elements into their workflows. Data were recorded on three separate occasions. The first was an in-person interview discussing an AR use case (March 2022) with an Urban Designer in a senior management position. Second, a hybrid (online/in-person) focus group expanded the discussion on the ongoing use of the AR system, plus an initial wider discussion of AR (August 2023). A third focus group in person opened into a wider discussion about other areas of potential interest for SC (September 2023).

I (this researcher) started working part time at Define (as Head of Research, October 2022), which allowed opportunity for the further expanded focus-group discussion and deeper appreciation of the projects and practices being discussed. The third session started with a 25 min presentation by me on key developing PhD themes and was followed by open discussion as a reaction to questions raised in participants' minds within this practice situated context. As this event was near the end of primary data collection, this especially acted to provide feedback and agreement disagreement on some of the core ideas as developed during this PhD. These focus groups included multiple members of the practice from different levels of experience (senior - 'Director', to junior - 'graduate') and discipline backgrounds (planning, urban design, and landscape architecture).


FIGURE 26 - EXAMPLE RENDER AND OFFICE (WEAREDEFINE.COM)

Adoption of a Simple Visualisation Service

Define had been increasingly using the AR visualisation tool True View, which they felt was now part of their standard practice for representing modelled ideas on site. 'True View Visuals' is an iPad application (*TrueViewVisuals*, 2024) allowing visualisation of 3D design proposals, as a geo-located, scaled on-site representation, which can be exported as still images for input into planning documents (e.g. Landscape

Visual Impact Assessment). Following the interview over a year earlier, participants noted that TrueView was still being used regularly across various projects. Certain, younger staff members individuals lead in its use as 'the expert' in its specific use.

It was indicated that a key part of the appeal was simplicity and automatic configuration. True View is set up as a service, not only an application. This includes the supply of hardware (currently iPads) which is set up with the software and ongoing technical support. They stated that this provides confidence as a 'known cost', which can be built into fee proposals. This was felt to greatly reduce the risk of trialling it, to see if it could replace an existing workflow. Over a short trial, it was realised that this presented a significant reduction in the time taken to undertake context-based design visualisation and was able to help convince stakeholders of design decisions about the scale and massing of development. The approach was considered to have some additional technical requirements to more standard methods (desktop CAD: Vectorworks) but provided an accessible visual format.

In terms of the process, the software requires the input of a 3D model, which was made as part of a wider design process. Using TrueView, work is sent to an external team, which then positions the model in the software remotely and sends it to the device software. On site, the AR system aligns to specific geo-located reference points for more accurate positioning. These points may be footpaths or obvious reference features, following standard survey methods. Participants said that they were familiar with these reference locations due to their ongoing involvement in the project; therefore, this did not present any difficulty in the process.

A significant benefit was felt in reducing the time and knowledge commitment, *PR-k:* "we were trying to transfer all these formulas and we were going into trigonometry calculators just to try and it was just trying to understand how it works", whereas "they it's what they do, it's what they're there for to offer that Technical Support so that we don't have to".

Participant *PR-u*, who is a graphic designer as well as urban designer, was particularly aware of general spatial computing discussion than others. They noted that the specific use case of the True View system was beneficial to practice, as it presented a clear use case. This is vs. the more open but less certain use of, for example, Adobe Aero, though there was note that such a scale can widen capabilities such as facilitating geo-spatial AR.

PR-u suggested that the capability of apps developed by large companies like Adobe or Google was less specific but brought key features that might be very useful in the future, noting particularly geo-spatial AR, which would seem useful. Discussing a proposed future situation, it was speculated that using Geospatial AR, where designers could put design proposals out for public viewing, might be useful, though this was met with hesitation that Google Glass (2013) made these kinds of promises, but it was too early at that time.

Though, *PR-q* pointed to potential barrier to entry if using an immersive digital experience, discussing from their personal view, due to their age and that they 'do not game' (video game) they generally find being immersed in a virtual world too surreal.

Visual Capability and Accuracy

The system can display proposals in a real-world context for the real-time analysis of design ideas. It was used primarily to test the layouts and heights of proposals to understand their visual impact. It was stated as "easier to see what is going on" and is adaptable to which viewpoint is selected on-site.

> PR-k: discussed how the immediacy of visuals aids in quick understanding, *"having had very limited* (previous) *input on this project" the "idea of being able to see this 'Crook Barrow Hill', simulated site experience, where you could "move the buildings around"… this one gives you the best view of this hill…you can walk around the site" and "make sure.." of the design. "it's really useful for that".*

In addition, the placement of a model into a visual scene was able to provide greater accuracy as a geometric process of producing visuals. There was some debate between Megan (PR-j), on absolute accuracy in terms of being able to use outputs for 'Verified Views' to support planning applications (i.e. as 'impartial reality' (The Planner, 2018) - 50 mm prime lens as human eye equivalent). The team suggested that it was possible to use it in this way by loading verified images.

Models can be inserted and viewed real-time, placing visual alignment, as 'calibration' of the image in space. *PR-k: "it's really useful to have that sort of augmented reality function. I think it's much more straightforward than doing it on Vectorworks",* similarly, comparing to Google Earth, one participant said that in G.E they could create a crude model, but when trying to place it into the view it wasn't at scale, it didn't place it accurately (did not automate, like True View). A noted capability was the ability to add layers of vegetation to the foreground to explore design options for screening the impact of a building in the landscape (technically as occluded AR or MR).

They felt that there was a need to develop a deeply rooted conceptual vision for each specific place. This includes telling the story of a site and how the design proposal connects to it, as well as how well this serves the community, which, in new developments, is how this will help to form a community. This is not about construction or BIM, but the broader strategy, including the sequence of inter-relating events, described as 'moving parts, including the timing and phasing of development which cannot be too prescriptive.

> Sophia Brown - *"if we're designing in 3D anyway on computer screens, it feels like the screen is really limiting us now", "it kind of takes away the point of it."*

Stage of design process

Discussion also pointed to the risk to design process of revealing too much information as provided by an immersive visual focus, and how spatial 3d models take things further. They reference a project where there is a need for local employment, which includes lots of local debate surrounding decision-making. As the proposals require the building of large facilities, there was doubt that making the visuals even more obvious and getting everyone's opinion could detract or sway against practical decisions. *PR-u "As soon as you see these big employment sheds in that location, it's almost got that negative (response) 'looks worse than you thought'".* *PR-q* suggested that looking at things in such an absolute, scaled reality (early on) could exacerbate the issue of people understanding proposals so literally.

Discussing participatory process, *PR-p* felt it was important to get engagement, going in 'too early' and asking locals to get involved in the various aspects of design process, did not work practically. As, asking non-designers to draw - will not happen, but spatial computing aspects could have a strong impact on this: *PR-p "having something that they can understand very, very quickly, in the time that they've got, this could really unlock that",* but *"there is an issue with the current need to put on a big headset in these kinds of social situations, it needs to not make people feel vulnerable".* Picking up on the 'AR walk' ideas from Reimagining Southside (see 5.6) as presented to them, PR-s: suggested that with this kind of approach, you could go *'relatively early',* if there is a basic framework for the project, even if not spatial – just the component library idea to aid participation. *PR-p,* agreed that there needed to be a basic frame of reference so that people can add things and have fun with it and not for the design team to not expect that this process will create a finished product.

PR-s argued that one of the dangers of a 3D model (more so, spatial 3D) is that, with such a fixed realism, people might feel like it is finished and that they cannot change it. The discussion followed what might be called virtual precedent studies. PR-s, PR-t both built on each other's comments, debating how to best enable the public response. Rather than the public being asked to produce a list of 'things' that might be unachievable, they could explore design response via experiential precedents. Virtual sites and elements would be a good way to understand what people like about certain conditions, and "could unlock different emotional responses", as "it can be tricky to describe thoughts", especially for younger people.

PR-w compared spatial approaches (their experience with True View) to taking a Plan to public events, as a fixed object/document that everyone can see simultaneously. However, they argue that this is not the way people see or understand design in the real world. Rather, they recall projects which have had a lot of debate around a plan by various discipline experts and the public, but it often lacks substance, that would benefit the 'seeing of the reality of the site-scheme' at the point of those discussions.

Minor Technical Issues

> Helen (*PR-n*) *"TrueView is almost brilliant, isn't it?"*
>
> *PR-k: "Yeah"*

Some minor technical issues of glitching were also noted, particularly related to being on site, which they suspect as being related to electronic interference from power lines or Wi-Fi signals. As regular users of the system, there were felt some areas that needed improvement. They discussed the user interface in general, and the processing and transfer of files between devices and between multiple devices. Using two devices, each required a separate setup process for the same project, doubling the workload.

> *Megan (PR-j) "each image you have to calibrate it to make sure that models are in the right place, and if an image is on both devices, you have to calculate both rather than just doing it once. It's a big headache. Makes it pointless having multiple devices"*

Even though the office uses the same IT system (Apple mac), Trueview iPads also presented some difficulties in syncing data. It was reported that the calibration was not always perfect, leading to minor inaccuracy of location, but it was usually 'good enough to get an idea'. Sometimes the rendering did not display correctly for which they were not certain of the reasons; possibly software, hardware (iPad), and data availability issues. They appreciated that the Trueview team was very small (possibly one person), so they expected that this would take time.

> *"There is designing in 3D, but then also us telling the story in 3D. So, if we have consultations with people"... "1000 homes are going to descend in their neighbourhoods… how can we use 3D to tell the story and navigate and show them the good stuff and get that message across?"*

Adoption of wider Spatial Computing

Aligning to discussions around covid19 and remote work, PR-p felt that that remote immersive communication might be useful, as the recent use of Microsoft Teams had already been quite useful: *"I don't have to go down to London twice a week", "Talking around a table, that's great as well, but for pure sheer convenience in a money driven world."*

More specifically, *PR-w* indicated that despite technological advances, there were professional and wider social constraints to adoption; as *"for Define as well for other practices, we are really indoctrinated by the process as well"… you said 'the technology has not caught up', but the process is years behind that…it's all about plans documents, printed stuff."* Conversely, *PR-r* suggested that in their experience in a past practice, the use of spatial technology had been embraced at the construction end of the process, such as AR to check specification on-site, but that it was not yet used the design process. They also had general concern aligned to their experience of dealing with BIM compliance, that smaller, design-led practices (such as Define) would be priced out of projects by the need to invest in equipment, training, and licencing.

Beyond such localised issues, it was also argued by PR-t, that ultimately *"politics can get in the way",* no matter the consensus, method, clarity or efforts put in by the team.

Local Government - Birmingham City Council planning team

The interview took place online in July 2022 with five members from the Birmingham City Council (BCC) planning department. The participants were highly experienced planners, two of which also had specialisms in using computer technologies, including exploring ways that spatial computing and city modelling/digital twin data might support council design review and decision making.

> *"There's not many projects I've worked on where I didn't wish that we had better virtual or augmented reality that we could call on to help us make design decisions, or to review somebody else's scheme"* Participant: *PR-g*

Capability and Access to Spatial Computing

The council team has built a VR room for design review as part of the planning process, which PR-e stated *"worked really well…well, quite well."* Whilst many specialist companies had offered solutions, but these were *"eye wateringly expensive"*, *"ridiculously over-priced"*. PR-d, added that for example, City View, *"it was £300,000! We could employ several people…plus it requires the constraint of a contract."* PR-e adds that *"Eventually, the council team developed their own in-house solution with off-the-shelf products, which included a workflow from 3D studio max and Sketchup into Unreal Engine"*. This sat alongside one new procurement for a 'stereoscopic 3d renderer (Visionary Render), as the senior manager wanted co-present environment for planning committee, but this *"didn't work… partly because of the implementation and"* people just *"didn't want to wear the glasses"*.

Whilst PR-h they had developed their own Unreal engine solution, loading in different design options (models) for discussion with a client. We are very interested in moving towards real-time design. This had been used to set up a VR room which fed into the planning process, where developers submitting a digital 3D model alongside traditional paper proposals, where, PR-e stated *"We can see in context, to check the validity of the proposal: to see if they're trying to 'pull the wool' over our eyes"*. This more truthful, open analysis was compared to the traditional photomontage, which it was stated was easy for the developer to 'control the message', for example, by selecting a favourable angle or scale. Using this process, PR-d indicated that the team were able to create a highly realistic model of a major city centre proposal for public engagement (Smithfield Market site). However, this lacked some useful functionality due to a limited in-house capability in programming and advanced physical setup to take it to their ideal solution.

Reflecting on this context, PR-e added that generally "There are solutions out there that can be really impressive, but they're not quite easy enough, or cheap enough, or accessible enough to be truly practical without putting a lot of money and time in". PR-d added that the technology is often not as functional as shown in promotional videos of people manipulating things and *"Having a quick workflow is really important", When considering what to go with.* The team had visited another council who had paid for one of the expensive commercial packages, though had doubt over the level of control and speed of making changes, as it was *"quite clunky" and frustrating in terms of interactivity, as changes to the model required the issuing of a request to an external team.*

There was interest in accessible systems, and they discussed their early adoption of AR, but, as PR-h stated whilst *"we tried AR around nine years ago, using smartphones and markers…the mobiles were not capable of running it correctly. It put off our director, to the point of not trying it again".* Reflecting on seeing a video of Arkio (from an earlier researcher's presentation), *PR-g added that whilst "I'm the least technical here…the usability is exciting".* There's *"potential for better understanding the scale of proposals, which is a regular consideration; for example, an ongoing discussion between the council ('us') setting ideal heights developers want to go higher. If it was possible to have these kinds of discussions as a collaborative process, it would aid all round understanding."*

Investment Requirement

> *"Councils are not typically on the cutting-edge of things, but using a city model, we were one of the earliest ones, as one of the largest authorities in Western Europe", whereas "Many smaller authorities do not have additional resources, such as specialist members, even to support the training of staff.* But *"planners do not typically have such specialist knowledge, or skills in computing" - PR-d*

PR-e discussed the uncertainty when investing in equipment and resources in a changeable organisational environment, both political and situational. After the dedicated VR room had been built, the building was subsequently sold due to pressure from Covid, as all staff were then working at home at the time (including at the time of interview). Reflecting on this, *PR-e* felt it was hard to know whether to rebuild it, as the sale of other buildings was uncertain. Additionally, for public engagement, this would require an even greater investment, which it was not currently certain enough to make practical, confident decisions, or even to know when the barrier would be low enough to do so. *PR-f*, added *"it's a lot of investment for a short time"*, which *"leads to things getting quickly out of date".* They felt that a process of picking 'flagship' projects might enable support funding and (external) investment, adding *"I think it's great tool. It's just how we can pay for it and make it happen".* Following this, PR-e suggested that the business case is much more robust where there are large projects, with large or multiple developers and the they are able to do public consultation over a longer time periods (10 years).

PR-h suggested that costs could also be lowered, with good forward planning to integration with upcoming projects, including precise utilisation of specific technologies.

In this context, PR-e suggested that there would be benefit in focussing on methods with proven accessibility, such as VR with 3D interactive online map (e.g. Google Earth /VR). Adding that *"if we're going to buy into something big, then you'd want something that is modular and adaptable and flexible".* Though, even though value of money and integrated solutions were key, it was important not to *"end up with a profusion of dedicated platforms that don't like each other, and all require their own investments".*

In summary, PR-e reflected, *"I think all this is fascinating. It's just it's really difficult to know, particularly when you got very limited resources; where to invest and what in, to go beyond that kind of initial step".*

In this context, PR-d suggested that there needs to be focus specific workflow, with a system that only needs tweaks, not a big investment (of time), such as extensive modelling requirements. Early-stage modelling could be more indicative and therefore less resource intensive. For the team, this raised questions around the appropriate level of modelling resolution (detail) required at early, design stages, where too much can lead people to see proposals as finished product, and led to focus on details that were not yet important.

Public Engagement

> *"If you go into details (too early), people think it's some sort of done deal…that's 'what it's going to be!'" - PR-f*

They debated 3D visuals in a document called 'Shaping Our City', with the aim that it was about "starting the conversation", to take people (the public) on a journey and to instil some ambition. They felt that a shared spatial overlay would be a powerful way to experience the proposals. For example: "find a safe spot on the A38, put your tablet there and actually see the carriageways gone, reduced to two lanes", "have some public transport, some trees," and then you can look around and see impact that would have on that space and being in that moment, in that space hearing the traffic, then you plug your earphones and you hear some birdsong, .. really make it feel – four dimensional." It was felt that where this (spatial computing) gets 'really interesting' is if the public can do it themselves, download it and see these things on site, or explore it remotely from their homes – 'lots of possibilities and exciting benefits'.

As a 'consultation' tool PR-e suggested that there was great promise for spatial technologies to make planning more accessible to the public. For example, geo-located AR could allow models to be positioned at their real world proposed location for public interaction and feedback. Though, there was concern that digital exclusion would need to be considered, as *"you can look at this beautiful 3D model if you've got a nice phone and good quality Internet connection, but we work in many deprived areas where people cannot afford the data".*

It was also considered that public interaction would need to provide a great level of contextual detail through detailed modelling of existing places to "*really look like the city, and you need to see the windows and the materials and the detail*". This was available to purchase, as PR-h noted as example, services by 'Blue Sky' who were starting to look at very high-resolution imagery using photography and drones (Bluesky, 2024).

Practitioner/Academic – Landscape and Urban Design

Context

In January 2024, participant (*AC-f*) who recently moved into academia following over a decade of Landscape Architecture and Urban Design practice experience, joined for one online discussive interview. They reflected on their practice experience using specific spatial computing applications, within a 'design delivery focused, and medium-sized practice in Birmingham. The interviewee also asked questions that sparked interesting areas of reflection.

Understanding space

> *"we've had instances, especially at public consultations", where "you realise that a lot people can't read plans in the way that designers do", "show them something in three dimensions and because that's their human lived experience, they can grab hold of it, they can interrogate it in ways that they can't do a two-dimensional plan. That has massive benefits,.. but the same time, it's really dangerous" - AC-f*

VR was seen in their experience of practice and was mostly considered a finalising part of the process. This was due to the need for a relatively finished model for VR, which, as an output, fits more towards the final stages of a project.

One of the issues they found when using rendered VR to show the design to clients was that it could give a false impression of completion and accurate design reality. Clients were unfamiliar with the technology. After seeing the design in such a complete way in VR, the client would expect that that was the final design and that we could start the building. As the designer, however, knew, many elements were not actually complete or fully worked out:

> "I was always wincing because I was like, but we've totally fudged that.. we have just put a plant over that junction because I know the materials do not work." - *AC-f*

Furthermore, once the scheme was built, there was a large gap between what the client thought they would get, having already experienced it in VR, and what was actually built. They recalled the client wanting photos at the same spots as the VR viewpoints for comparison. In VR:

> *"The plants were all fluffed out in the beds. The trees were perfectly symmetrical, plumbs.. no chips and scratches in things", "I just always felt like we kind of undelivered" [in the real build] - AC-f*

This was felt to be even more of a problem when engaging in public scrutiny when it was not ready. The designer is held accountable for what was published. They argue that this is something where greater education about the nature of the design process is needed. In this context, they highlighted a conflict between the prerogative of delivering a design vision and defending business reputation.

Collaboration

Discussing a co-creation space within (Revit BIM), they found that everyone working together had issues with various model changes occurring concurrently. Even with what is called 'clash-detection' function of the software, they found that for effective workflow, they needed to work outside of the collaborative environment at certain points. This allowed them to use functionalities missing from the shared capability, such as applying rendering to see for example, highly visual, material compositional changes, see which parts are "feasible, but just not desirable". Summarising, this they argue, "yes, we have this amazing technology, but it can if you don't have the competency in the office"

Academic in Visual Communication, specialist in Immersive Technologies

The following summarises a short interview with a lecturer Visual Communication, participant *AC-e*, who has long standing personal and research interest in immersive technologies (and science fiction). From the hands-on experience, they found immersion to be a profoundly engaging experience. Though SC seems new, they have been following its development since the 1990s, a development they describe as a long, sometimes journey with various disappointments.

They believe that the ecosystem is highly important to get right and needs alignment with the mindset: values and expectations of art- and design-focused professionals. Reflecting on the current dominance of Meta for mainstream SC, but with very gaming and media orientated mixed reality headsets, they have high hopes that Apple entering the hardware space will bring a better aligned interface and approach that closely matches designer aligned ways of thinking, such as strong ergonomics, friendly interface design, and consistent and stable performance.

> *they hoped that "subtle differences make quite a big difference"* [considering the upcoming Apple Vision Pro] – *AC-e*

They expect that there will be many further ethical questions as capability develops, but some of these we just do not know about yet. They felt a strong need to consider the impact on future life to look ahead.

Software Developer - Unity Reflect and Review

In December 2021 two professional representatives from software company Unity ('game engine') were interviewed to discuss the then new products 'Unity Reflect' and 'Unity Review' (UR/R). Though, most of the discussion (data collected) was by technical expert participant *PR-c*. The UR/R software aims to offer greater accessibility to collaborative spatial computing for the built environment ('BE') industry (specifically: Architecture, Engineering and Construction, or 'AEC').

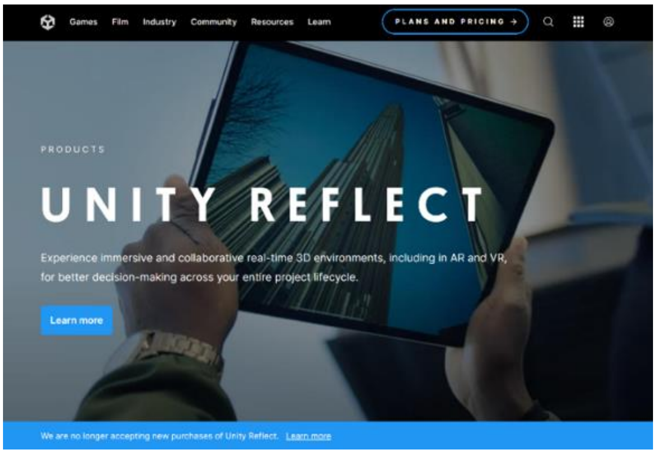


FIGURE 27 - UNITY REFLECT, 2023

The tone and direction for much of the interview was heavily directed towards promoting the technical capability of the software. Unlike the interview with Arkio to follow, there was a general avoidance to discuss points of reflection, or status and limitations of spatial computing. The participant account therefore can be seen as presenting a picture of the underlying commercial evaluation of SC (aims and decisions), that had influenced specific choices of software design and capability by Unity as a company. Much of the discussion focused on how they felt the range of technical capabilities were aligned with professional goals of built environment professionals. The participant account is representative of trained, promotional responses, with some occasional elements of personal professional opinion. Later discussions focused on social expectations and the systems and how they influenced social interactions; and these answers generally felt less rehearsed and more of the participants own volition.

Alignment and integration with Built Environment software and modes

The participants presented a need for accessible use, both in terms of the users experience and in connecting to BE software. Generally, capability was claimed to be simple, with 'no computer developer' (coding) knowledge being required to use the main functions: *"Simple buttons"*, that 'every user could access *"without effort*". In addition, the reliable transfer of built environment model formats into and out-of game engines, e.g. stated examples: Revit, Vectorworks (Building Information Modelling, BIM software).

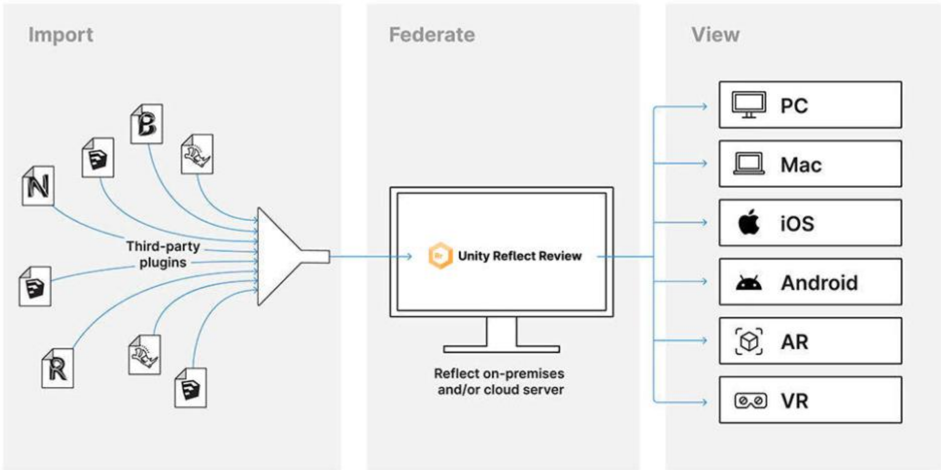


FIGURE 28 - INPUT AND OUTPUT FORMATS (UNITY REFLECT 2023)

The context for these considerations, is that built environment (/AEC) professionals have been increasingly using game engines which enable dynamic, immersive 'world building', and more recently AR/VR options. However, this has also presented challenges in terms of additional resources: time and skills to use game design software. This is often quite different to BE aligned software, and adds requirements for advanced computing knowledge, such as computer coding (C# Unity), to gain access and capability to the more advanced functions. This is especially the case for AR and VR capability and/or multi-user ('multi-player') features allow collaborative, multidevice use: desktop, mobile, headsets and so on.

As such, specific examples and illustrative workflows were discussed, such as the ability to copy over lighting effects and specifications from Revit, retaining ability to turn these on-off in unity reflect as well as ability to create visual effects in Unity R/R based on prior data: colour, graphs, charts of production timeline, etc. There was strong emphasis of wide and easy compatibility with many 'standard' (BE) file types. BIM, was mentioned specifically as 'building information' being essentially the same as Unity's capability with metadata. Though BIM is construction stage focused and has less specific relevance to urban design. However, there is relevance to potential use with equivalent use of such metadata for CIM (city information modelling), though a much less established area. The researcher asked specifically if metadata could link to all types of specification, for example horticultural specification databases for green spaces. The participants discussed 'SpeedTree' as a tree modeller, though this seemed to align more strongly to rendering game landscapes as high-resolution models, rather than plant specification (for example, UK National Plant Specification), (or other types of construction).

Interactive, Collaborative, Networked Capabilities

There were also claims towards facilitating collaborative working as a core capability. 'Hosting and syncing', was felt to be a key factor for success, where up to 25 users could concurrently join in to the virtual design space, with ability to see and speak to each other as part of design review. The researcher enquired as to how, to what extent and in what conditions this could adapt to, though these further specific details were not disclosed, it was suggested later that users it will be engaging, facilitating social interactions between designer and viewers.

It was argued that the capability of Unity R/R was not just about the visual quality provided by game engine quality rendering, but the many practical collaborative functions, including design interactions such as ability to, e.g. *'measure, place objects: surfaces, walls, place at any scale'*. For "*those not familiar, or less tech literate"*, a 'presentation mode' was considered a key collaborative selling point, allowing 'experts, to give a tour'. They indicated that users could engage from various platforms, for example using mobile, with a 'fingers first' approach (user interface design for touchscreen); joysticks for strong movement around model. This was 'simple!' and accessible by different users.

Aligning to traditional project management approaches (i.e. more consultation, than participation), collaboration can be handled by a hierarchy of access, by allocated roles: managers, designers, viewers. The cheaper, Unity 'Review' version is a more limited offer allowing only the viewer role, where only viewing and comments is enabled (no design actions).

Aligned to these capabilities, connection to cloud-based virtual models was enabled, as 'a connection to the Metaverse' (unlimited realms and layers of virtual worlds), a term they described as 'a flavour of the month'. The term was particularly promoted by Meta around the time of interview (*Digital connection in the metaverse | Meta*, 2023), though also subsequently saw reduced emphasis after much critique in popular media (Mac, Frenkel and Roose, 2022)). It was presented that small file sizes were needed to facilitate quick sharing of outputs with stakeholders: "only a download 70mb", to "easily interact with proposals" (i.e. downloading on a mobile device using mobile data).

This also connects to the idea of digital twins, where virtual models act as a clone and test bed for the real world. However, these general statements did not go into detail about the experience of Unity R/R users connecting specifically or explain why they thought it would benefit design process – the benefit was perhaps assumed and seemed rhetorically stated.

A fully functional and adaptable product

The participant promoted that overall, the software was good value, as being low cost (relative to typical BE software), as well as reliable, and adaptable. This 'allowed a simplified front-end' (user interface), making accessible an advanced, real-time and interactive renderer (game engine). It was stated that game engine's native ability to dynamically rendering only for the users real time view, including for example their level of zoom and for their specific device settings, allows more efficient rendering (computer resource allocation, by increasing or reducing polygon count). This was felt to be of particular benefit to mobile, AR, VR formats, where resource efficiency is imperative, and in comparison, to typical BE software, which often renders the whole model, or one scene in very high resolution.

Aligned to this, it was stated that the UR/R augmented system now worked on "any surface, whether in domestic or business contexts" by using markerless surface analysis and tracking, though use in exterior (more challenging/variable) environments were not mentioned. This was likely wanting to be seen as close to current trends and capabilities in AR (markerless tech as an advancement from previously 'marker' based).

Current Technical Limitations

Though there was an emphasis on positive promotion (sales), some points of limitations were identified, especially framed in a process of 'continuous development towards future releases, a 'roadmap' towards:

- Larger models, up to 1tb file size
- Tetherless VR (no cable), run on 'Quest/Hololens', which had a 'light version but same functionality'
- QR codes, would facilitate further cloud-based sharing with stakeholders

In addition, other limits were acknowledged. Firstly, that visual quality would varyby hardware strength, for example, users wanting real sun, advanced lighting would 'need a better graphics card'. Similarly, VR capability required a tethered headset (with connecting cable), such as Vive, Rift, or Quest with cable.

Additionally, there were experiencing a challenge in ability to integrate a global positioning system (GPS), as they felt that the good systems were too expensive, and the mobile systems not able to be accurate to under 5 meters precision. As such, they were working on QR codes as current solution (i.e marker-based positioning, and not markerless in all circumstances, as previously stated). The system was presented as a live demo to the researcher and did come across as stable and capable system as described. However, the participant did make comment in minor frustration - 'it's doing that again', hinting at an ongoing issue.

A difficult (emergent) software market sector

As of late 2023, the Unity Reflect website (Unity, 2023) lists Reflect and Review as discontinued and framed as 'no longer accepting new purchases'. This is representative of the uncertain commercial market in which SC products still sit, even when developed/backed by a very large company such as Unity (revenue ~$2.1 billion year) (GamesIndustry.biz, 2024).

Software Developer - Arkio

> *"co-design software is still a particularly emergent area" (Chowdhury and Hanegraaf, 2022).*

In 2021 and 2022 an interview took place with Johan Hanagraff (*PR-v, named participant*) head of product at collaborative spatial software Arkio, who is also *"an architect and engineer specialized in design technology"*, he *"believes immersive technologies have the potential to redefine our design process."* (Arkio, 2023). The interview followed a more general discussion on spatial technologies a year earlier, with more specific discussion on the current application, limitations and future potential of the Arkio platform.

Arkio is a multidevice 3D collaborative modelling software primarily for VR devices and desktop though also AR. It can be used to *"Design interiors, sketch buildings, and craft environments. Mixed realities and experience design options on-site. Collaborate anywhere using VR, desktop, and mobile"* (Arkio, 2023). Arkio was later to play an increasingly significant role in this research project as a chosen softeware for 'CoLAB' research events.

Spatial computing: a real benefit for urban design?

Johan felt that the primary benefit of VR and AR, is the spatial perception and validation of scale of space and 3D components, where this brings these elements to a user's physical surrounding, as experiencing the spatial properties of a design, "you don't need to go back and forth between a representation of a 3d object on a 2D screen", it is a direct experience.

Though still a pre-release 'open Beta' at the time of a first meeting in 2021, the Arkio software was subsequently released as a commercial product in 2022. Johan discussed that most spatial computing technologies are designed by gaming artists, but a few with architectural interest (such as Arkio) are moving into the SC development space. He expected to see more people moving into the world building; "you just replace the foam model by a digital asset, that you can bring with you very easily".

It was suggested that AR (using mobile devices) currently has more significant limitations for modelling owing to the need to hold the device. Unlike head-mounted systems with controllers or hand tracking, holding the device reduces the freedom for both hands to manipulate the design. It is useful for design review, using digital pens to add for marking up: that is, drawn notes, or sketches, which is not very precise thing to do using the handheld controller. More generally, he found that software development is more difficult owing to the significant strengths and limitations of different devices.

Transitioning of Skills

Before the interview, I had tried Arkio, and one thing I was not able to do was work out on how to rotate an object. Johan stated that the easiest way to rotate is by reaching into the geometry, picking it up and rotating. I asked if maybe this is an interesting psychological transformation because I'm embedded in traditional approaches. Johan - “you're not alone”, in “feedback sessions with users, they're drawing in Sketchup first” and say *“‘I want to draw an outline first and I want to do this’” … but “the baseline is, you're working with volumetric shapes that collide and join and interact with each other when you're moving them and picking them up”.*

Johan stated that the mobile and the PC app are a bit harder for people to understand, but clear in VR because user can ‘pick it up’ and see it gluing and snapping together. He suggested that from the user studies, people tended to learn how to use Arkio quickly, especially younger people and that the main difficulty was learning which buttons did what, with the control interface being new to them. His usual method for teaching people is showing them what the buttons do, and when they have a go, he finds they pick it up quickly.

> *“we already limit down what we do with the buttons... we already have the grip, the trigger, and the two buttons on the top to the same. And that that's still a lot for people to take in.”*

One of the capabilities of Arkio is that multiple (24) users can co-design together on the same model within a shared virtual space. This differs significantly from the typical single-user approach of traditional modelling for architectural design. Johan suggested that by comparison, traditional approaches were inefficient because of the separated processes, options and formats that have to pass between people at different stages – rather than them being able to all look at the same time.

> *“Often the client gets invited at fixed position at the end of the process. Like the collaboration doesn't happen in Revit, or Sketchup”*

5.2 Exploration of Spatial Computing Systems: outline Testing and Analysis

Although technical exploration was not the sole focus of the study, it was important to establish which hardware and software solutions would be viable, so that specific spatial computing approaches could be applied. Primary consideration factored in a limited budget and then specific application and capability within certain areas of the design process, judged by prior experience [as discussed in researcher reflection 1.6]. This aligns with typical conditions in the real-world context of practice and academia, where there is a need to fit into a range of resourcing considerations. A weighing of the value to delivery compromised by different elements was needed. There is no specific budget to explore the latest cutting edge, but even if so, the current landscape of choices, each with compromises, as well as the rapid pace of development (and obsolescence), does not present clear choices. The initial review started with a broad assessment of typologies, moving towards testing of specific applications on available devices, and then towards the specific choices that would be used in future research events.

Collaborative Design Communication – Established vs potential Spatial Computing

Through systematic review of contemporary research (2010-2021) exploring commercial software for AEC, Yu et al., (2022) conclude: *"academic research about immersive virtual environments ImVE support for design collaboration, is not keeping pace with the accelerating rate of its technological advancement"* (*immersive virtual environments). In addition, the focus of research has often only included software that is clearly targeted for Architecture, Engineering, Construction (AEC). There has also been an emphasis on 'construction' stages in software being made available, and much less testing in early-stage conceptual work, and/or practice aligned situations. For Urban Design, although construction is the ultimate aim, that stage is often a long way off. There is also a very different focus on creating conceptual ideas and diagrammatic framework design. For this early stage, software not directly designed or specified as for AEC, especially in the early conceptual phases, could also be useful; for example, software such as Google Earth VR for site-analysis stages, or Gravity Sketch and Open Brush for form making. The following sub-chapter systematically explores this issue. The following table compares established methods with spatial computing formats, along with a suite of approaches that are used in the design process. This has been conceptualised throughout the research process, based on background knowledge and reflection-on-action.

TABLE 14 - COMMUNICATION TYPES, COMPARISON OF ESTABLISHED VS SC EQUIVALENT

Communication Format	Format - Family	Established/Standard Formats	Spatial Computing Formats
Visualisation	3D model	Physical or Digital Model Scaled Lay person: Plasticine, paper, cardboard Professional: CAD, laser cut, 3d forming,	(simulated) Physical Model, Scaled Immersive human scale Tactile Interactive/ manipulation
	2D image	Printed, shown at scales Plan and Sections 2D (of 3D) Iso/Axo	Infinitely, Interactively Scalable Place anywhere (including 'floating')
	Sketching	Freehand on paper, drawing surfaces, tablets	Freehand in space, or simulated paper/surface
	Film / Animation	Screen / Projector	Infinitely, interactively Scalable Place anywhere (including 'floating')
Writing	Annotation	Notepad, Post-it	Notepad, Post-it (simulated / replication)
	Planning, Brief writing	Text Document	Notepad, Post-it (simulated / replication)
Spoken	Audio Capture	Device capture: Mobile device ('Phone) (MD)	Device capture: mobile MD or head mounted device (HMD) Spatially positioned/suggestive native
ALL	Management	Collaboration Manager, BIM software	Integrated visual interface, situated in world view, aligned to site, activity locations

The following table (13) summarises the researcher's categorisation of broad software design related capabilities, and how these differ or relate for AR and VR.

TABLE 15 - CAPABILITY TYPES - SPATIAL COMPUTING (SC) CURRENT TO MID-2024

Key Examples	Augmented and Mixed Reality (AR/ MR) *mobile and head mounted	Virtual Reality (VR) * head mounted
SOFTWARE		
Development / Operating systems	AR Kit (Apple), AR Core (Google) Horizon OS (Meta) - formerly VR, now MR visionOS 1 (Apple) - vOS2 Autumn 2024	
3D modelling – integrated	Unity, Unreal Engine	
3D modelling	Sketchfab, CityEngine Unite AR, ARLOOPA, AR elements	VR plugins for Revit, Sketchup, CityEngine
Drawing, Graphics	Just a line, clipdrop, Artivive, Artsteps	Tilt Brush, Blocks, Graffiti VR
Mapping and Location	Streetview AR	Google Earth VR
Communication / Social	Pokemon Go, Snapchat, Instagram (filters)	VR Chat
Integrated collaborative interface (multiuser/tool)	Arkio, Unity Reflect/Review *discontinued Spatial.io, Hubs VR (Mozilla) *discontinued	
HARDWARE		
Desktop Computer		Sony Playstation PSVR/PSVR2, Oculus Rift cv1 / 'S', Valve Index, HTC Vive, HP Reverb
Mobile Headset	MS Hololens (1/2), Magic Leap 1, Google Glass	Meta Quest: Go, 1,2,3 Pro, (previously Oculus); Pico Neo 3,4, Apple Vision Pro
Mobile Phone	Thousands of apps for all types, particularly Apple and Android	All legacy, replaced by mobile headsets (Quest 1/2), but previously Daydream, Cardboard, Gear VR

Figure 31 - Arkio Wheel Captured From Personal Device

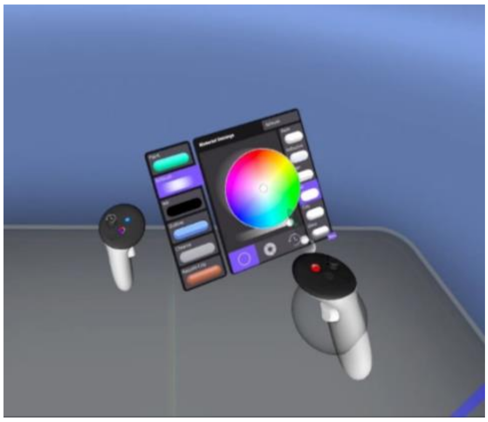


Figure 32 - Gravity Sketch Palette Captured From Personal Device

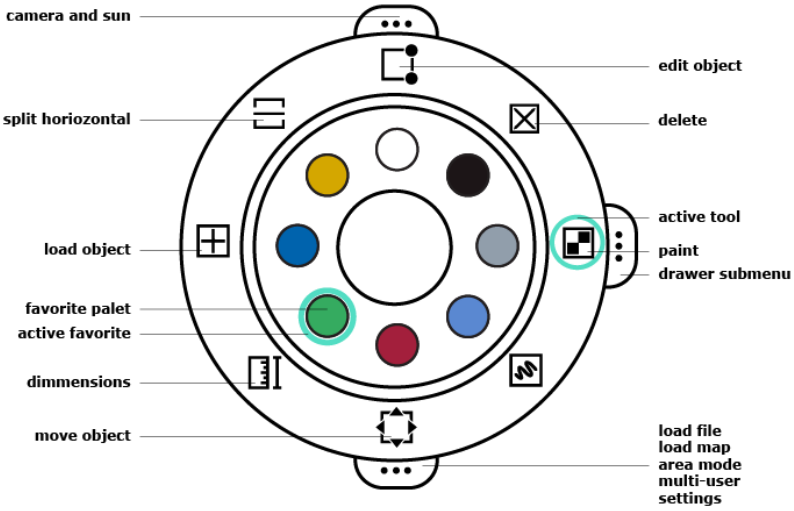


Figure 30 - Arkio - Wheel – As Physical/Mechanical Panel (Arkio.is - Accessed 12/03/2023)

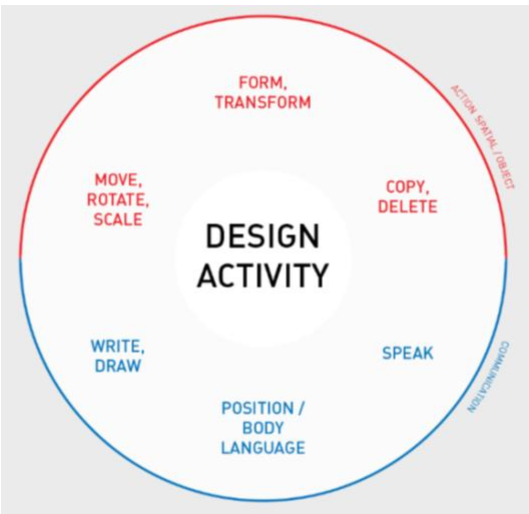


Figure 29 - Ideation Of Design Actions (Author 2021)

Evaluation of SC software

The following applications were tested on AR- and VR-capable devices for suitability for use in the research project – see table 13. Scores were given relative to current capability (not future promise) and are intended as an outline assessment on suitability and potential use to this project. This is ordered from most to least useful. Scores are allocated by testing and judgement on the following three factors:

1. Capability – range and sophistication of actions, interactions, specific UD and collaborative requirements: large and human scale, immersion
2. Access - ease of use, availability/cost
3. Stability – positioning, clarity on available hardware available: *AR – Google Pixel 6 Mobile Phone, VR - Oculus Quest 1/Rift S*

TABLE 16 - TESTING AND EVALUATION OF SC SOFTWARE

Name Type / Hardware	*Evaluation comments*	*Avg*	*Capability*	*Access*	*Stability*
Google Earth VR VR HMD	Translation of all the key features of Google Earth into VR. Very easy to use, highly engaging, if limited interaction. Model of the Earth - zoom into aerial photos, with basic 3d buildings/topography street views.	4.7	4	5	5
Open Brush VR HMD	Artistic drawing in 3D space, at human scale. Similar to Gravity Sketch - same use case, smaller scale design. Open source version of Google Tilt Brush (discontinued)	4.3	3	5	5
Arkio multiplatform AR, VR + desktop HMD, AR mobile/HMD	Interactive, collaborative, multiplatform 3D modelling - appropriate for UD scale. A showcase for how VR can provide a way of building designs that feels like physical building in space. It is still in development and though less capability than full modelling software (i.e. Rhino, Revit), there is potential benefit in simplicity- feels a lot like Sketchup. Hard to use, far less capable via Mobile AR.	4.3	4.5	4	4.5
Gravity Sketch VR HMD	Design, modelling and drawing in 3D space, at human scale. Comprehensive but focused on small scale modelling. Very smooth capabilities for drawing in 3d space, very engaging. Would work well for small scale sculptural models. Does not have features for handling architectural or above scales (urban design)	4.3	3.5	4.5	5
Unity Reflect Multiplatform	Implied version of Unity tailored to 'AEC' - Architecture, Engineering, focus on collaborative design review. Very capable, aligned to use. Allows	4.3	5	3.5	4.5

workflow BIM to Desktop	simplified process - instant interaction between architecture and XR in Unity. Focus closer to Construction, BIM. Paid for, or limited time license, no resource for extended use. *No longer available				
SketchFab VR Mobile - android, iOS	A 3D model service combines with others, (too) wide range, many high quality models - only some are optimised as 'AR/VR ready' (filter), model types focused on media not UD. Almost too much choice, not tailored to UD uses. AR seems to no longer work directly from mobile app (used to). Would require significant budget to pay for individual models.	4.0	4	4	4
Spatial AR, VR + desktop VR HMD, AR mobile/HMD	Open platform, environment for design review and discussion, has a welcoming, design studio feel about it. Other than placing design items and discuss them, not sure what the application is for as has no design, modelling features, drawing/notes are quite basic. Update 2024 - changed to focus on use as a game platform (reduced score for UD capability)	4.0	3	4	5
Unity Foundation Development Platform Desktop	Multi-functional, immersive software development platform ('game engine'). Extensive possibilities. Used in previous Colab, with Vuforia for basic AR, most Architecture/Design students found very difficult to learn in the timeframe/reluctant to learn another complex software they would not absolutely need in future.	3.7	5	2	5
Niantic Lightspeed AR Development Plugin Unity	Unity Plugin = potential cutting edge AR. Would add very stable/capable AR, but too complex for built environment type students/public. As above, for future bespoke software development, collaboration with computing/games depts.	3.7	5	2	5
Fologram AR, MR Mobile - android, iOS Hololens	Technically capable modeller, but focused on Architectural scale, construction - displaying one intricate model, connects to other Arch software, attuned to displaying / reviewing detail including mixed reality, caters to design complexity and precision with layers and measurements	4.0	4	3.5	4
VR Sketch VR HMD	Translation of Sketchup capability to VR. Not able to test as need Pro Sketchup license. Needs tethered headset for interactive/collaborative modelling.	4.0	4.5	3	?
Kubity / Kubity Go AR/VR Mobile - android, iOS	Simple, non technical ways to quickly convert and show Architectural type models (Sketchup and Revit). Works very smoothly in initial testing. Is limited in scope currently only works with Skp, Rvt. Essentially it simplifies 3D models to AR workflow - output of showing pre-built work on mobile AR. Also tried with architecture and interior design students in a collaborative module last year. They liked this one the	3.8	3	4	4

	best due to its simplicity and alignment to software they were already using.				
SketchAR Mobile - android, iOS	Uses AR to teach digital drawing. Education service, range of tutorials for learning how to draw has a useful side aspect, though less useful within live, more time constrained design process. Could be useful to train/guide those less familiar	3.8	3	4	4
Augment AR Mobile - android, iOS	Collaborative AR, platform - viewer with simple professionally focused interface for connecting models. Very stable. Cloud storage and load users models, 2D elements	3.5	4	3	3.5
Thyng AR Mobile - android, iOS	AR viewer, multiple elements - stable placement and interaction. Focus of models and interface more towards gaming than professionals.	3.5	3	3.5	4
Depth Lab AR Mobile - android, iOS	Fun but uncertain use case for UD. Consistently near to stable. Each feature/ effect is quite fun. Especially the physics interactions. These are fun games, but not certain how they would be used. As elements cannot be made bespoke - only using the apps presets, it is hard to see how it could be applied for use any stage in UD. Perhaps to get users to be playful in their early AR testing	3.5	2.5	4	4
The Wild AR, VR + desktop VR HMD, AR handheld or HMD	Open platform, collaborative environment for design review and inter-personal discussion. Very similar to Spatial, collaborative environment - design review/studio space. Now discontinued/ acquired by Autodesk, not able to test further. Was very similar to Spatial (*Merged with Autodesk Workshop XR - after testing period).	3.5	3.5	?	?
Unite AR AR Mobile - android, iOS	Create own (3D model app) Capable, specific use cases, but expensive - Very stable once placed, moderately large library of presets - range of styles, but seems not much 'urban' elements, some architecture. 3D model displays as 3 types: 'service', Image (marker), Ground Plane (markerless). Can upload own models (paid service). Picky about surfaces. Easy to move, scale, rotate Can only place one model at a time. Generally, this is a service/website and app to support building 3D model AR, without needing to use a game engine, etc. All done through browser. Pricing seems very high for relatively basic capability.	3.2	3.5	3	3
AR Loopa AR, future VR Mobile - android, iOS	Placement of 3D model - very similar to Unite AR technically/UX, but less appropriate content - aligned to product marketing, sales	2.8	2.5	3	3

FectAR AR, future VR Mobile - android, iOS	Placement of 3D model - very similar to Unite AR technically/UX, but less appropriate emphasis on pop culture references rather than more serious uses, therefore lacks useful models	2.8	2.5	3	3
Clip drop AR Mobile - android, iOS	A camera auto-editor: specifically a background removal tool, similar to Ps. Simple function, lacks capability. Relatively effective, certainly with simply defined objects (taken as 2D). However, this is a very limited definition of AR, particularly as it doesn't map the object in 3D and has no ability to place the object back into the space, only copies to desktop (clip 'drop'). Could be a useful tool generally, but very specific application.	2.7	2	4	2
UrbanAR AR Mobile - android, iOS	Demo - potentially strong future capability, currently limited. Range of objects is limited and not categorised. Though enough to demo. Tracking works very well, stable using (android) ARcore. Moving and rotating models works quite well. Hard to move objects up/down, or place them accurately, cannot scale them (they are set at 1:1 though). Very similar to Unite AR technically/UX, but less appropriate	2.5	2.5	3	2
Just a line AR Mobile - android, iOS	Early 'Tech Demo' (Concept) - Draws lines in space. You can share* drawing activity with a partner (*not tried). Not very useful for representing design ideas, as does not remain 'in place' or at original scale - loose tracking if moving significantly. Is too simple - lacks drawing capability - options, weak accuracy/precision. Fundamental problems for design use.	2.3	1	4	2

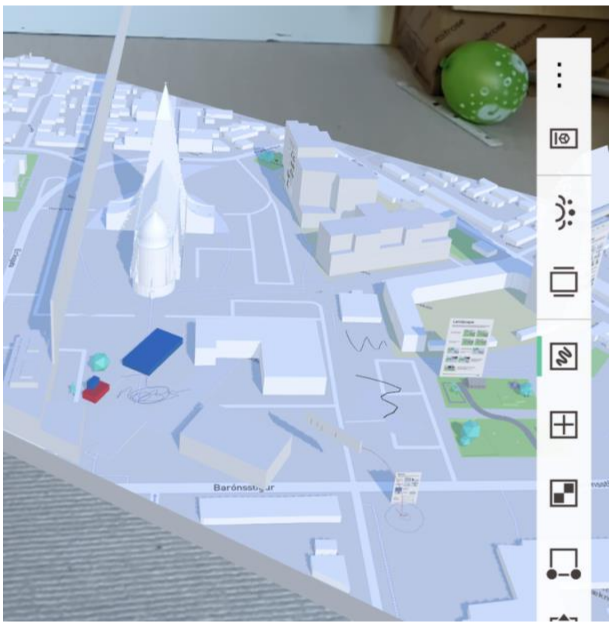


FIGURE 33 - TESTING ARKIO MOBILE AR, STABLE BUT HARD TO MANIPULATE WITH TOUCHSCREEN

5.3 Pilot Events: testing technology and methods

Between 2021-22 a series of six pilot testing events were undertaken to apply spatial computing within short student activities, to explore and test appreciate technological, collaborative design events, and research method considerations. Firstly, AR and VR hardware setup and selected software applications (see 5.3), testing under more challenging, dynamic, multi-user settings. Secondly, to test research design and event activity methods (design activities), with loose relation to simple design actions such as playful design creation (loose brief), or collaborative interaction (design review) as straight-forward use cases. Lastly, it provided an initial outline appreciation of participants broad perceptions and reactions to SC with relation to the research questions. This included reaction to videos of example SC and discussion points around the future of spatial technologies (presented by the researcher).

Summary of the events:

a. A 1.5-hour long online session (video-call, due to Covid19 lockdown), with 36 undergraduate architecture students, split into three discussion/application groups. Three AR apps were installed and tested using personal mobile phone and laptop devices. Apps tested were: Spatial and Arkio multi-user, virtual design space, and Adobe Aero, VR model creation and display. The task was to explore possibilities: attempting to join the space collaboratively, upload and discuss a pre-prepared model, add and manipulate objects and media, reviewing what was possible. Guidance on tool use was given prior to the event.

b. Three 1 hour technical demonstration and open design exploration sessions. First with 7 Postgraduate Landscape Architecture; Second with 5 Undergraduate Landscape Architecture and 5 Design Management students, Third with 4 Postgraduate Urban Design students. This included a presentation by the researcher and then users trying out Arkio and Open Brush software with VR headsets (Oculus Rift S / Quest 1).

c. A 3-hour exploratory session, presentation and conceptual exploration future AR and potential impact on professional practice.

d. A 1 hour, presentation and discussion session with a small group of members of the public from African/Asian countries

These events performed largely for researcher reflection and fine tuning of approaches, though contributed to some participant data points directly. The pilots were also useful to highlight wider organisational and resource issues, both technical and social/organisational.

Technical Testing and Demonstrations

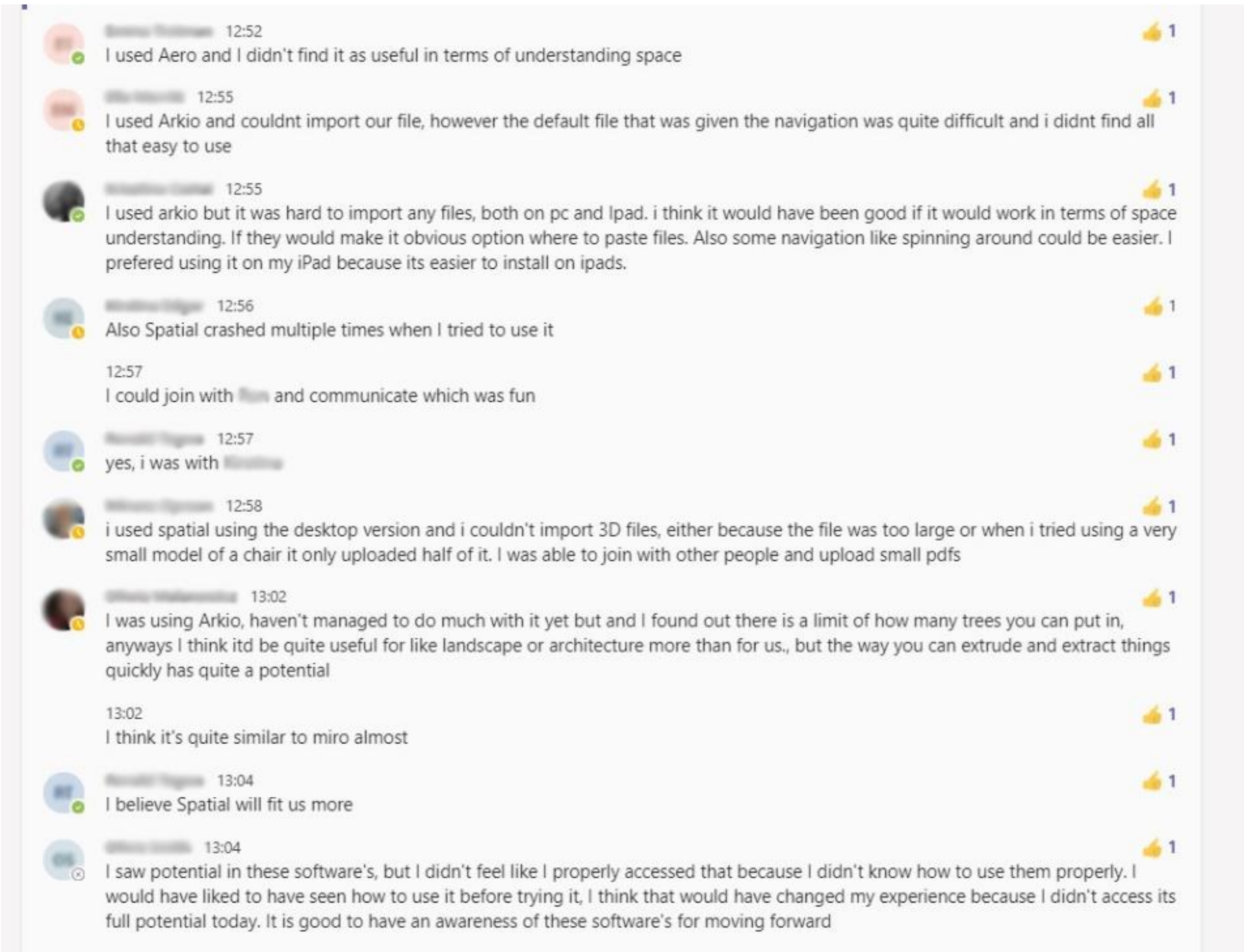
The events highlighted a range of technical issues to be overcome. When testing on users own devices, the variability of devices and user knowledge/skill created lots of uncertainty, including varying ability to navigate the space, or have successful interactions within. With AR especially, users experienced multiple crashing (especially using 'Spatial'), which was something also experienced by the researcher on their own mobile phone. Generally, participant More time was needed to appreciate the technology, as it was unfamiliar

For technical demonstrations that relied on student preparation, there was a general lack of preparedness, such as many not installing the apps, nor fully read brief in advance. The online sessions were particularly challenging, as, it was not possible to directly see or relate the participant experiences (actions) or interactions with AR or provide technical guidance. It therefore relied heavily on their verbal and text responses as explaining perceptions.

There was a reduced range of issues were set up by the researcher, using known equipment. But there were still issues, especially with the tethered headset (Rfit S, Oculus link software and Alienware pc), which on multiple occasions was inconsistent in connection to the pc, multiple restarts of the hardware and software until working correctly. For example, responding to an extended delay and rather awkward situation, one participant a senior academic (AC-a) joked sarcastically *"This is a good advert for VR, isn't it?"*. The range of technical issues often damaged social flow of the events and added a performative pressure.

Discussion and Conceptual Explorations

Points of discussion were raised regarding the nature of accessibility, incorporating spatial computing elements into the design process. It was discussed how SC might improve sustainability, through publicly iterated design that is more likely to be locally accepted before time and resources are committed. It was also discussed how it might open new areas for research. Specific discussion led to thinking about connecting spatially located emotional responses with GiS to inform deep, placed-based design analysis. There was also some concern that the gap between Blind and Partially sighted people might be increased further by future overreliance on such visual approach, pointing to potential to enhance sound, touch sensory perceptions. In addition, that mapped analysis from SC technology might be useful to trace users' spatial actions and needs.


12:52
I used Aero and I didn't find it as useful in terms of understanding space

12:55
I used Arkio and couldnt import our file, however the default file that was given the navigation was quite difficult and i didnt find all that easy to use

12:55
I used arkio but it was hard to import any files, both on pc and Ipad. i think it would have been good if it would work in terms of space understanding. If they would make it obvious option where to paste files. Also some navigation like spinning around could be easier. I prefered using it on my iPad because its easier to install on ipads.

12:56
Also Spatial crashed multiple times when I tried to use it

12:57
I could join with and communicate which was fun

12:57
yes, i was with

12:58
i used spatial using the desktop version and i couldn't import 3D files, either because the file was too large or when i tried using a very small model of a chair it only uploaded half of it. I was able to join with other people and upload small pdfs

13:02
I was using Arkio, haven't managed to do much with it yet but and I found out there is a limit of how many trees you can put in, anyways I think itd be quite useful for like landscape or architecture more than for us., but the way you can extrude and extract things quickly has quite a potential

13:02
I think it's quite similar to miro almost

13:04
I believe Spatial will fit us more

13:04
I saw potential in these software's, but I didn't feel like I properly accessed that because I didn't know how to use them properly. I would have liked to have seen how to use it before trying it, I think that would have changed my experience because I didn't access its full potential today. It is good to have an awareness of these software's for moving forward

FIGURE 34 - STUDENT DISCUSSION EXAMPLE (FROM REMOTE SESSION ON TEAMS)

5.4 Long Event: CoLAB: 'CoReality Brum'

Event Context

The following case details a project January to May 2022 that aligned an academic-taught module to a practice competition entry for strategic urban design. Academically, the event sat within a long-established, yearly occurring taught module which was specifically designed, specified, and promoted to be adaptable to various ways of collaborative working: Collaborative Laboratory (Co.LAB) (Birmingham City University, 2024). Student and academic participants were directly involved for all, or specific points for ten, weekly, 3 hour long sessions. The sessions and background work by the participants followed a build-up of collaborative work as a design process.

The design project was a conceptual exploration tied to a competitive bid by multidisciplinary practice WSP to work on an ongoing strategic planning framework called 'Our Future City 2040' (Birmingham City Council, 2023) (also referred to in BCC interview – see 5.1). The project sat within a stated element of the WSP competition entry, under 'public engagement' (though it did not involve any financial or contractual relationship). A WSP representative (PR-i), who is a senior Urban Designer and leads the WSP competition entry, joined this event at key stages. For the student designers, this participant sat in a role of key 'stakeholder', as a reference point for design briefing and for reflective guidance on their developing ideas.

The title 'CoReality Brum' brought participants to focus on the concepts, CO: Collaborative process; Reality: real and extended (augmented/virtual) reality; and local place context 'Brum' (colloquial), the UK City of Birmingham. The design project itself involved the production of various strategic design visions for two key wards within the outer city centre.

Students participants' discipline of study varied, as did the level and range of understanding and skill. The brief intentionally focused on the design and site context considerations primarily, as fitting what would be the case for any design project. spatial computing elements were a significant, stated 'exploratory' element of process, but not an exclusive method for design production or communication. This approach was used to survey the perception of SC within the diverse and changeable conditions of a specific design project. The overall aim of this approach was to try to attain more genuine insight from design-project contextualised reactions and reflections. Participants' actions and responses were recorded to try to understand the potential usefulness, limitations, and future considerations of specific SC elements. For example, did these new methods add to, detract, speed up, or slow down processes? Why did the participants think this might be the case? What and how might they change these outcomes as the project develops?

As such, participants were tasked to practically test and conceptually explore a selection of SC tools within a longitudinal, collaborative, multidisciplinary (urban) design process. Participants:

- A highly experienced Urban Design practitioner as key stakeholder (from WSP, Birmingham office)
- Ten students studied architecture/landscape architecture at the degree (year 2 of 3) and master's level. They did not know each other before the activities.
- An academic module leader and other academics who joined at certain points.
- The author joined for most sessions, including to instigate the project, facilitate the spatial computing aspects in technical setup, demos and to discuss design visualisation options, as well as to observe the key development and formal design review points. I was unable to join two critical sessions due to illness which presented specific impacts to facilitation/resourcing.

The Design Project

Two mixed-discipline groups each focused on one different strategic-scale site in the Hockley and Edgbaston wards, each with different socioeconomic and infrastructural conditions. An urban design approach: strategic, large scale, with a conceptual 'vision' as an output and indicative smaller scale areas as more tangible, in-depth examples. Specific contexts and aims were largely derived from the project partner's current practice focus for specific areas that aligned to "Our Future City. The overall aim was for design thinking to move outwards from the prior focus of the central city core to the immediately adjacent surrounding areas. This presented a large-scale project, which the stakeholder and academic both reflected on at the end, as perhaps a bit too complex for the students, alongside the need for multidisciplinary collaboration with subject areas and design scale they were not familiar with Urban Design, and SC applications.

Five key SC activities/stages are discussed in detail in this section.

- Real site visit vs Virtual site visit; Desktop vs Remote, VR
- Viewing of examples and discussion of potential AR/VR
- Exploring and testing a potential SC solution
- Final design proposal outputs
- Participant reflections

Site Analysis in VR

> *"1. I don't think I'd have to go to the site!*
> *..2. you definitely have to go to site!"*
> *..3. What do we actually do when we go to site?*

Before participants visited the real site in person, Google Earth (G.E) VR was used to explore the site virtually. This was set up with one Oculus Rift S VR headset, tethered to VR capable laptop at the side of the studio space with 2×2m open area, with participants were seated around this space, with freedom to work in their own process, viewing and interacting with a 'VR zone'. A screen was set up to project the view from the headset to facilitate collaborative engagement and interaction.

FIGURE 35 - ROOM SETUP RIFT S - GOOGLE EARTH VR

Individuals entered the virtual site, using the aerial and 'Streetview' tools in Google Earth to explore their sites, guided by others on navigation and aims for their site analysis. Being very close to the desktop version of G.E which they stated was often used. This general capability was very familiar to the students. Hence, this approach was useful for discussing the exact benefit of VR.

Immersion in Place

Repeated statements from different participants indicated that the feeling of a 'sense of the place' and 'sense of scale' of space and objects more directly was the key benefit over the desktop version. They also felt that this understanding was easier, not needing as much interpretation as it would be on a 2D screen.

Although with some shifting of opinion and contrast in views, it was primarily considered that G.E VR was still not close enough to replicating the dynamic of a real site visit to fully replace an actual site visit. This was in terms of missing the life of the place; feeling the spatial, material, and elemental details that were not captured; or giving the opportunity to investigate what is still a static simulation. This included the lack of additional senses, such as smells and sounds, which they felt was needed to really benefit understanding as a benefit to the design process.

FIGURE 36 - VR WAS NOT ABLE TO FULLY REPLICATE THE DYNAMIC CONDITIONS OF THE SITE (HOCKLEY, BIRMINGHAM)

Although discussed repeatedly, the participants were not able to further articulate in detail how the meaning of this experiential-scale benefit was useful more specifically, or how this experience contributed tangibly to a design process. In more practical ways, there were agreements that the VR version was particularly useful where someone was not able to visit, such as the at the time very current, for example pandemic lockdowns (Covid19), or more widely, the site being international and/or with significant financial, or time constraints as a project. In this case, they felt G.E VR would make both cheap and 'as close as possible' to a real site visit, with the above benefits over the desktop-only version.

Likely the benefit of the VR version, is not an either-or scenario and there is nuance in appreciating where it fits for each project, as one participant stated, *"it's benefit really depends on the context and what you are trying to find out"*..

Several factors need to be considered before drawing wider conclusions, several of which are part of the module discussion. First, this is only one piece of software with specific limitations that are mostly true for the desktop version, such as lack of interaction. Specifically, for G.E_VR, we also need to consider that aerials are not always available in a similar mapped resolution, or having Streetview, as mapping depth varies from country to country. More widely, the level of photographic – lidar-scan detail could be improved, which is a limitation of freely available software. It was also discussed that drones could potentially be used in the future to use these basic principles, but for remote interaction with the actual site, taking mobility much further.

Social, Cognitive effort: from 'Wow' to How?

On entering G.E VR, it was noticeable that each participant made an emotive sound: as a 'wow,' 'woah', 'ooh' or similar. This seemed to be an instinctive reaction to the visual stimulus. As the session progressed, this moved towards practical conceptual discussions around how it was used to support the understanding and assessment of site context information.

Participants reported or were observed as showing cognitive and performative considerations related to VR use. VR and the particular setup we used seemed to have an impact on and be impacted by the additional experiential effort of going into the VR world. Similarly, there were considerations relating to self-conscious awareness and social performance pressure with relationship to group dynamics.

> *"You've got the VR face!"*

One participant who spent around 20mins exploring the site in VR, was particularly vocal on their emotional status *"Woh, that's so cool though…You actually get lost"*. I ask, <u>How does that feel coming out?</u> *"Feels like I've just woken up again."* <u>So you were dreaming?</u> "Yeah!" and over 10 minutes later, *"How long was in that thing for..?"*. This highlighted a lengthy period of emotional adaption in transferring between VR and the studio.

FIGURE 37 – GROUP PARTICIPANTS, MOVED BETWEEN COLLABORATIVE AND SEPARATED ACTIONS, BASED ON DIFFERING TECHNOLOGIES AND STAGES OF DESIGN ACTION

Observations indicated that between the group and the individual in VR, the level of interaction increased through the session as the design task became clearer to the group (specific place analysis). This appeared to relate to each individual, their confidence, and their social role within the group. For example, those individuals most socially confident in the situation (not just with VR) who lead the group dynamic were also the first to use the equipment and created the most discussion between those in and out of the headset. These were mostly MA-level students.

FIGURE 38 – THE SINGLE USER VR SETUP CREATED A PERFORMATIVE EMPHASIS SUITING SOME MORE THAN OTHERS

Uptake and Engagement

Nine of the participants tried out the G.E VR experience, with the level of time inside varying from 5 and 25 minutes each, some with repeat uses. Three members did not try this and were reluctant to do so. They later stated in private that they were concerned about the reasons for social or physical comfort. One participant stated that the headset would cause problems with their hair/makeup. Second, a previous VR experience made them feel nauseous and that they were already dizzy that day.

There was a sense that the room setup, as stated previously, added to a sense of focus on the individual and pressure of social performance. The combination of being in a socially active process (design activity) and entering into an isolated experience (VR) resulted in reluctance. With VR still being relatively novel to many of the students, there was uncertainty. Whilst the more confident, this promoted intrigue, it seemed to place pressure on performance and focus on them, bringing an additional sense of nervousness ('stage fright').

AR and VR in Design Process

Discussing potential collaborative platforms, the participants were introduced to Spatial.io, Unity Reflect, and Arkio through an on-screen demo. Spatial was downloaded by most participants to their phones and laptops, where we joined a co-design space as a demonstration of multi-format AR, VR, Desktop, where participants could join the same virtual space, and that space could blend with the real-world studio using AR (mobile phones in this case). The general discussion was in comparison to 'Miro' and 'Teams' as a platform, for which students had recently become very familiar due to remote and often collaborative work during Covid19 restrictions. Though set up on the VR headset, only one student tried this view and for a very short time, commenting – *"it's alright, it has potential"* (S-r). The other students wanted to try on their own devices. Several trying the mobile AR in this live condition (including the researcher) all indicated some technical issues, such as the app not loading correctly, or having difficulty correctly scanning the rather complex environment with the various (real) tables and chairs, surface patterns, textures and people in view.

Arkio and Unity Reflect were discussed as working alongside 3D design software, such as Rhino, Revit, and Sketchup. Due to unexpected absence of the event facilitator for this stage (the researcher), the demonstration and exploration was not undertaken by participants, for which the setup relied heavily on individual access to the technology (software and hardware), as well as specific knowledge and experience of its technical setup (this researcher), where backup facilitation support was not possible within the short timeframe.

The student participants were tasked with exploring ideas and choosing one method of AR or VR to incorporate into their design process. Although discussion through the bulk of the module showed general intent and interest in exploring AR and VR solutions for design process, all ultimately focused on its use for the final presentation of their work. Both working groups settled on displaying a 3D model of their proposals using VR to present final proposals (to client/stakeholder). However, the specific approach for each group differed, in direct relation to the specific combined skill set and project management decisions, as follows.

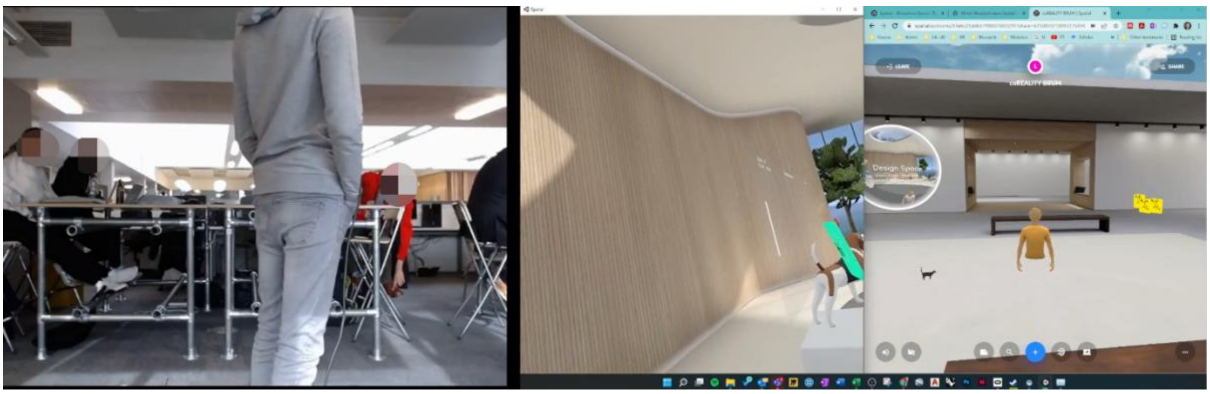


FIGURE 39 – DEMONSTRATING SPATIAL

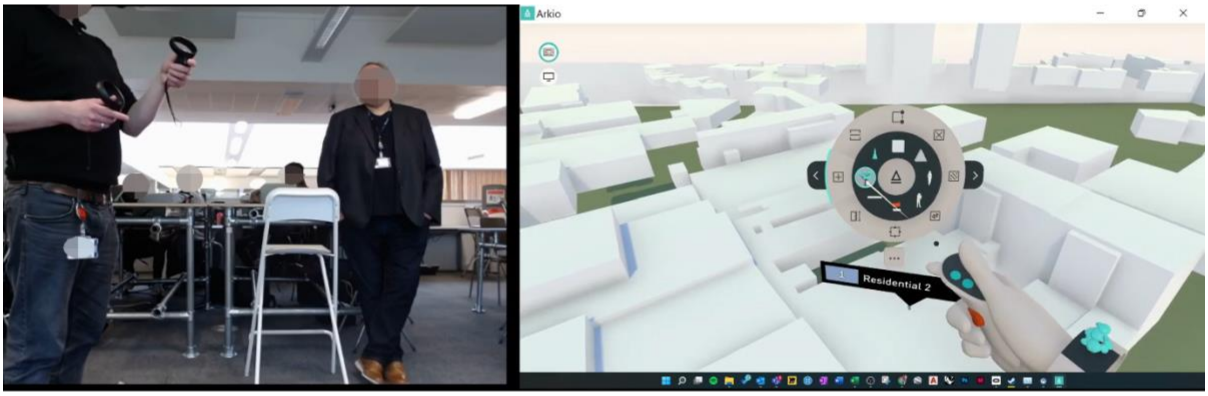


FIGURE 40 - DEMONSTRATING ARKIO

Influence of Group Dynamic on technical choices

Approach 1 – 'the Tech Guy' – developing a standalone app using Unity. Group 1 relied heavily on one team member for VR output. This participant had much more experience and knowledge than others, as was evidenced through an extended capability to discuss and create using specialist computing in a general sense and VR specifically. This applicant was able to develop the 3D model using the 3d software Blender (e.g. not a typical 3d package for architecture) and created a bespoke application using Unity (game engine) for their own Quest 2 headset. This allowed the placement of a 3D model of their design proposal into the space, alongside basic navigation in and around the project by the user. This student essentially led the VR aspect for their group, acting as a specialist, and developed the technical aspects of their solution over several weeks. They did this in a remote way, so it became clear that they appeared less connected to the collaborative discussions during this stage of the process.

While this was a strong technical achievement in a timeframe of two weeks, the practice stakeholder, in trying the experience at the final design review, was not very impressed. They felt that in terms of the design and visual communication output, it was weaker than what would have been produced in 'simpler, standard software' (*specifically Sketchup), although they added that the other more traditionally produced work was also not excellent. Clearly, this approach, with high technical requirements, had taken time and effort away from what the experienced designer felt were much more important tasks – i.e. process for 'good design – good visuals'.

Approach 2, the easy bolt-on, using Enscape for VR. The second group at a late stage, made the then time pressured decision to implement the easiest solution of using commercially available Enscape rendering software to output a 3D model of their design proposal to VR. The late stage of use also meant that the immersive experience was not used in design process to review and iterate the design beforehand. Whilst Enscape presented a very stable and easy-to-implement solution of immediately high graphical fidelity in lighting and materials, it was also rather undynamic as an experience. Except for ability to move around, interaction was limited and with no option for reviewers to record their feedback tangibly, e.g. manipulate, draw, leave comment. It also presented a rather static (lifeless) 3D world. This presented very little persuasion for the key stakeholder to engage in its use beyond a very quick tour of the design.

FIGURE 41 - FINAL DESIGN RENDER USING ENSCAPE SOFTWARE

Visual and Design Benefits?

There was some diversity of thought among the participants. Most student participants felt that there was a positive impact in a broad general sense of potential and being glad that they had the opportunity to explore ideas in terms of their own development. They also broadly agreed that the visualising, experiential sense of scale, and emotional response to experientially interacting with proposals was a key benefit. However, the participants were generally not able to expand with any depth of explanation as to why this was a benefit or evidence how it was a benefit to their design proposals. At the end of the project, participants were surveyed to reflect on their experiences. One of the master's students felt that it had no, and in some sense, a negative impact, though they stated this was not inherent to the specific VR technology, but due to their general lack of experience and exposure to ideas and current applications of spatial computing, including a lack of introduction in their prior studies, or practice experience.

The stakeholder participant (PR-i) had similar thoughts in overall assessment, adding that using a simpler, more understood software (specifically: *SketchUp desktop*) would have been quicker and easier, so that more time would be spent on the design than understanding the tech. This comment seemed to be in direct response to the Unity developed app however, one of the most complex methods that could possibly have been undertaken, and which was developed by one student through their own interest and expertise. Conversely, the student in question felt they had gained something in their own specific area of interest, in developing technical skills and with benefit to their future explorations of SC use.

Reflecting on the whole event, the stakeholder (PR-i) and academic (AC-c) participants both felt that overall, the students did not really embrace the exploration of technology. They were somewhat overwhelmed by the urban design project in general, and specifically (overly) concerned with the other more standard elements of the task, that is, competing challenges in complexity of design, ongoing collaborative complications, and external pressures.

Influence on Collaboration

Technical setup and social/organisational factors influenced collaboration greatly, including variable group dynamics, peer perception, and preconceptions, had a significant influence on success through the timeline of the event (10 weeks). The social dimension was more influential (often detrimental) to successful use of SC than initially expected and led to the revision of follow up research methods. Similarly, wider organisational arrangements and access to staff, equipment and wider IT (particularly secure networking limits) decisions impacted collaborative capabilities. Similarly, the technical set-up and practical inclusion of SC in such a complex process of urban design highlighted a range of challenges, including what were felt by participants to be large gaps in current areas of capability, making its use feel tokenistic ('random', 'bolt-on'). Numerous barriers were also presented by the technical limitations, which presented a limitation for participants to further understanding.

Summary

SC examples were incorporated into three key design stages, with varying success:

Site Analysis – Remote virtual immersion in visual site data (using Google Earth VR) was tested extensively over a three-hour session and follow up discussion. This compared desktop and real on-site analysis. Some benefits over the desktop version were indicated such as enhanced spatial awareness/resolution. Underlying limitations presented by both VR and desktop systems, such as lack of interaction and visual fidelity, were also emphasised by VR. Broadly, the specific VR system was felt to not replace the quality of understanding gained from real site visits but was able to add to site perception beyond that provided by desktop.

Design Development: examples to support conceptual ideation (e.g. Spatial, Arkio) were shown and discussed as having great potential, but ultimately were not used extensively by participants. Various factors influenced this but primarily, there were several issues of specific resource and technical setup complication, which then influenced engagement and ongoing belief in the systems. The setup relied overly on one facilitator (the researcher), and use of specific equipment – including headsets of very different setup: one mobile (Quest 1) and one tethered (Rift s) with powerful pc laptop. This created a complex, often unreliable setup process. This also presented a barrier for participants easy access to use outside of an overly extensive setup process, except where one participant had their own equipment (Quest 2 headset).

Design Review/Presentation was used to show final design in two technically quite different ways by the different collaborative groups (interactive-low poly, static high poly/render). Whilst this had some visualisation value and novelty, it was not highly valued by the participant designers nor design reviewers and each approach presented limitations to interaction and lacked extensive engagement.

In making collaborative decisions, students indicated various, repeated, and general perceptions of the benefits of design and understanding design, though they were not able to articulate deeply how or why this might be. Under complex design project conditions, the use of SC was placed in a supplementary position. Final outputs defaulted to use of only the most established use case of VR to communicate the final proposals.

The event was useful to further develop key understanding and considerations that were built upon in the research design of the studies that followed.

FIGURE 42 - VR SETUP - FINAL PRESENTATION TO STAKEHOLDER: OF SECONDARY IMPORTANCE

5.5 Short Event: ‘Reimagining Southside AR Walk’

“In some ways faster, in some ways slower”

Event Context

In May 2022, this event involved two, repeated two-hour long, live in-situ participant sessions on an early summer Saturday morning in the Southside district of Birmingham City Centre, UK. Southside is a designated character area, consisting of ‘Chinatown’ and ‘The Gay Village’, which form two distinct but slightly overlapping areas. Three academics were involved, including this researcher and a Southside Business Improvement District manager (off site, but advising on set-up/their aims). It also involved members of the public who had signed up for the event, following advertisements using local social media.

The research data for this PhD sat within a wider, separate research project with a community urban design focus. The data included here focuses only on the use of Augmented Reality, specifically an ‘AR Walk’ method for public participation. This included comparison to ‘photomapping’ and perception-based visual survey, as well as on-site and reflective discussions with some of the participants. The level of engagement by the public participants varied through the exercise, but consisted of between 10-15 people for each session, some in small groups of friends and/or couples. They were mostly younger adults who lived in the area or had direct personal or professional relationships with the area.

FIGURE 43 - CONCEPTUAL IMAGES MADE USING AR, USING PARTICIPANTS PERSONAL MOBILE PHONE

Augmented Reality selection and technical testing

Following previous experience testing software options (5.2, 5.3), it was decided early on that a single application would be needed to provide clarity of process and instruction to participants who would likely have no experience with the software. The app needed to be simple and intuitive, as participants (and additional researchers) needed to gain familiarity in a short period of time (< 1 h), not to spend time learning a complex interface, or a variety of approaches and interfaces of different apps. The review of AR apps took place in a limited timeframe for researcher exploration, with decisions made over a few days and with a focus on feasibility relating to available hardware (pre-owned mobile phones, rented iPad tablets), and within the expected situational conditions. This also aligned with the expectation that the target aims of exploring publicly available applications for use in public participatory situations would similarly often be time, resource (and skill) limited. Therefore, app selection followed a short process of testing a handful of downloadable AR software on personally owned hardware that could work in the project (Apple iPhone 12, Pixel 6, Android), which also aligns with the typical personal devices that would be used in the data collection event. iPads were used with the aim of their larger screens aiding the seeing and manipulation of content, as well as the ability to create a pre-setup system for easy, immediate participant use.

Testing by *AC-c* and the researcher reviewed various mobile apps available at the time, found that all had abilities and constraints. These were considered broadly as needing to be accessible to the conditions of the project: lay-persons, hired and personal hardware available within budget, range, and ability to display the type of 2D/3D design content desired. Potential AR apps were quickly narrowed down to those that provided a simple focus on displaying digital elements in an AR view. The following apps worked on both Android and Apple devices, with further quick judgements made through hands-on testing:

- Thyng (selected) – provided the smoothest, consistent operation: placement of objects, stability of tracking, worked similarly on both devices and systems (both on apple and Android). Although much of the default content via the inbuilt library was inappropriate, we were able to easily load in samples of our own 3D/2D content via mobile network uploads.
- *AR Viewer* – struggled placing multiple elements, interface lacked clarity of operation
- *Augment* – at that time, it would not work well on the Apple device, though it has some clear networking benefits. *It was used in the follow up project for reasons explained later [see - 7.5 Colab RSS]

Technical Selection and Setup Considerations

An equally important consideration was digital content. The 3D and 2D representative design elements were tested as options for use in AR apps. These were considered in terms of technical suitability and contextual appropriateness, assessed in terms of benefits and drawbacks, as the follows:

3D models

Benefits:

+ Significantly, can be easily placed in the scene, has good tracking, and responds well to manipulation. Can move around an object and scene in space.
+ It potentially allows rendering, lighting, and occlusion to match the scene.

Drawbacks:

- Models difficult to find and/or expensive to source, to form an appropriate, consistently presented library of elements that represented the desired conceptual design intent. Most models available were game-related assets (e.g. hyper-real media/fantastical themes) and did not provide a large database of assets of that were realistic, or of architectural type or quality.
- The variety of file formats added complexity/resource requirements for handling and conversion
- 3D models often presented additional hardware demands, particularly for placing multiple objects. Additionally, larger file sizes needed to be downloaded and to work remotely on multiple devices. This added to requirement for good networking, and which varied due to various participant devices and location/position on site.
- Such a varied, inconsistent body of styles of modelling did not give a consistent look or feel was considered might confuse participants and give too many options. This might then lose focus on the idea of representing a type or idea, rather than style, at this stage of design ideation: early stage; participatory urban design process.

2D images

Benefits:

+ Allowed the use of quickly created photo-based (inherently photorealistic). 'Cutout' elements, images can be found on multiple online databases or quickly created using photo-editing software.

+ Photographic 2D is more naturally integrated into the real visual scene in a place. This was also expected to be straightforward to comprehend, despite being a novel method.

+ Technically, presented low processor and bandwidth requirements (for networked, mobile devices) – meaning many files could be shared, and able to create more complex layered scenes as directed by participants' desires.

Drawbacks:

- Does not place or track so well for manipulation. Requires that the view be static once chosen. Limited form of spatial freedom, limited in terms of technical AR.

FIGURE 44 –AR OVERLAY: CONCEPTUAL REPRESENTATION USING PHOTO 'CUT-OUTS', FOR EXAMPLE, 'ELEPHANT IN THE ROOM' (SOMETHING NOT ON THE LIST / AN ALTERNATIVE)

Technology and Design Choices: Both 3D and 2D images could have been used together. However, 2D images were selected as the key form of representation for several reasons which fit the conditions of the event and team time resources. The primary benefits of more easily allowing highly appropriate design representations and of being a lower rendering requirement. The collection and processing of 2D images is much less time-consuming than for 3d models. This method resulted in what could be described as a kind of 'live image editing' (photoshopping). This allowed views to be chosen by the viewer (participant) and additional elements to be augmented to the view.

While the 2D elements provided these benefits, they also created a situation of reduced stability in placement/tracking and ease of scaling of imported elements within the AR scene, compared to 3D placement. All the approaches were found to have a strong degree of compromise.

For participants, this slowed down the process of placing design elements, and many participants were frustrated or otherwise held back in the speed of the process.

Content – use of analogy

Following technical testing, a library was developed to provide the participants with elements that could be added to their scenes. Considering the scope of a library, aims for participation might indicate a need for participants to be able to choose from an open and unlimited library of elements. However, this is both difficult to create (is not freely available/accessible) and, in addition, such an open remit may actually be more difficult to navigate in a short time by less experienced users. Therefore, it was decided to produce a manageable, carefully selected set of elements that represented broad types of elements that could feasibly be added to a scene. The decision positioned the role of design experts' facilitators, who worked to balance participatory freedom with practicalities of application.

The bespoke is a small library of options for participants to choose that loosely represents a typology/analogy. This intention was communicated to the participants as part of an introduction to the activity. For example, as Figure 40 shows, nature/vegetation (trees), somewhere to sit-socialise (tables, with umbrella), something unusual/fun (elephant).

FIGURE 45 - PHOTO ELEMENTS PLACED INTO SCENE BY A PARTICIPANT

Summary of Key Results

Overall

> *"I'm really impressed. I mean we have picked up. So, it's relatively easy"…"You have, I'm struggling".*

The use of AR in a public exercise brought initial excitement and engagement. The key ability to represent visual ideas instantaneously facilitated discussion, engaging users in debates. Users were immediately impressed by the automated placement of design elements into the space (scene). This increased accessibility to design visualisation, allowed quick placement and allowed the design/research team to quickly obtain a sense of what might be key desirables from the area (e.g. particularly more trees and seating). However, confidence in the method was reduced over time, as several disruptive hardware and software issues and limitations were found. Broadly, perception varied between participants, with some finding the quick prototyping useful, whilst others found it too imprecise to efficiently use in the design process.

Some of the issues which presented themselves could be reduced quite simply by repeated attempts with improved content library, research design choices and/or with access to more capable equipment such as head mounted, e.g. head mounted AR vs touchscreen (via increased budget). However, many issues were due to current technical limitations related to widespread hardware and software context, and participant's lack of prior exposure, leading to uncertainty using the technology. Due to participant questions, it was required to explain certain limitations caused by the method choices, particularly the 2D vs. 3D options. There was a gap between the ease in which people expected the technology to perform and actual compromised choices the research team had to make.

Usability and Interface

All participants required some guidance and discussed a learning curve. Observation suggested this was in any case a relatively quick process, though the extent of varied by different groups (age, where used personal devices). Difficulty for users often related to the use of the touchscreen interface to place the digital content in 3D space (augmented) as well as the software design.

There were some broad differences of opinion as to whether it was an intuitive method, though one participant expressed frustration, suggesting it was "not the most user-friendly interface" (PU-f). There were various interface challenges presented, such as in layering multiple objects, with overlaid boundary boxes, difficulty selecting, scaling and moving the digital elements in the augmented space. Similarly, difficulties were found in terms of selecting content from the library, the screen being too sensitive, and therefore pressing of the wrong 'buttons' (software). One user 'lost' all their elements, due to scaling and sensitivity issues, making everything too small to select.

Participants highlighted a need to enhance learning of the user interface and system, particularly for design tasks, where participants experienced ongoing issues with positioning and scaling

- Learning system: How to change the orientation, the angle
- Facilitator needed to guide – 'rotate is with two fingers'
- Keep pressing the wrong button
- Quick and intuitive, lack of precision in touch screen interface makes you looser
- Once you have a few objects in the scene, it becomes easier.
- "trying to get the scale right"
- Could do with a plan view so see where the objects are
- Needs to lock the placement
- Hard to layer up many things, control them (overlaying boundary box, cannot select, move easily)
- Tricky when they come in smaller (some elements importing at a tiny scale)

As a Design Tool

Participants presented differences of opinion on if AR was genuinely useful for design. There was strong positive sentiment given to the immediate placement of objects as an engaging process, *"From this moment, we don't need to use Photoshop, this is much faster" and "It feels like a game to create an image".* Conversely, some practical design features were seen to be missing, such as lack of a plan view *"to see where the objects are"* and similarly *"to relate the perspective to a strategic view (plan), connected to Google Street View".*

Towards the end of each session a few participants were skeptical, suggesting the AR elements were not precise enough, or at least were not fully understood enough to be used perfectly. Aside from the this, the ability to choose photorealistic elements provided a means to engage users to discuss their thoughts on a range of issues, from homelessness and public safety to the nature of politically driven planning process. Though these issues where not captured fully with the AR system, only prompted, and by the limited library. The use of conceptual images created interesting points for discussion about what the participants wanted in their design and around the subjective nature of their representation. It was useful to represent design using images that do not represent an absolute fixed idea but are open to interpretation. One participant added that there was a need to consider bias, in library selection so as not to "control the narrative"

Most participants knew a lot about the area, discussing aspects such as the lively atmosphere "the buzz", independent shops, community spirit and character, plenty of places to eat, 5 min walk to station, for regular travel and so on. Whilst it was not intended to seek capture of such sentiment, this revealed potential for an AR system to capture such details.

One participant stated that their interested in the AR walk was a more participatory approach, as they felt that the council's intent was often tokenistic, stating that "the council 'Consults'…and then they end up doing it their own way". However, it was still uncertain the extent to which the AR method helped or missed various aspects of locals site understanding and analysis, with its particular approach (prototype) and various associated limits. One participant was especially critical of the method, feeling that it was not too different from more traditional, physical method: *"You could take a photo and sketch on top, which would be the same thing* (as the 'AR walk' method), asking, whilst *"it is a fun way…is it actually more useful?"*

Technical requirement and limits

The 2D screen using mobile devices was felt to be a limit to immersion and spatial design as *"hard to express in a 3D space".* The iPads were more cumbersome and heavier for holding up and designing with over longer periods. One of the iPads would not load the software correctly and could not be used at all, being hired devices this relied on setup and testing by an external group. In addition, as the iPads were not mobile data enabled, they therefore had to 'hotspot' to researchers' mobile phones to access the shared library. This worked well in proximity but had a limited range. This range of considerations, added to setup complexity.

Many participants immediately or over time, found a preference for using their own personal devices, which were 'lighter, more capable (*newer)*' (and likely more familiar). However, in a final summarising discussion participants indicated that the experienced challenges with spatial objects and menus not being seen correctly (too small), as being a drawback of such small screens: *"Larger screens* (are) *needed for usability"*. There were also found to be issues using the screen in direct light, presenting a need to increase the brightness (which was not further possible), *"cannot see fully in daylight"* and perhaps needed a non-reflective screen cover/coating.

5.6 Long Event: CoLAB Reimagining Southside

Event Context

From January to May 2023, this research event followed in a similar mode to the previous event: CoLAB: Co.Reality Brum, as being situated within a live, ten-week long collaborative module involving three mixed-discipline student groups, supporting academics, and practice stakeholders, including members of the public engaging with student-led explorations. It was situated in the same place context (social-physical conditions) as Re-Imaging Southside - Public Participation (*RS-PP*), though nine months later, in what is a changeable urban context, with an entirely different participant mix. There were also several changes to the methods related to different conditions, including some intentional mitigation of limits inherent to previous events. Within this content, approaches were revisited for further testing. Generally, the event was exploratory, with a focus on early-stage design objectives which were defined by the participants and informed by a 'key stakeholder' and public stakeholders. In the later design action-focused sessions, students (only) tested transdisciplinary co-design within a shared VR environment. The aim was to build on emergent themes and methods, with further testing to refine and deepen the analysis.

For the participants, there were two main phases,

1. Defining the brief, context analysis, including public participation and
2. Design development using a direct collaborative method.

These phases had somewhat different set-up and objectives but were conceived to allow the student participants to experience them as part of a connected design process, that is, broadly, with design analysis informing production of design proposals. As with previous cases, this allowed participants to test the potential influence of spatial computing elements on in-context collaborative interactions, design actions, and outputs. Responding to difficulties presented in the previous 'CoLab: Co-Reality Brum,' the project area/design task for this event was simplified. The combined output of smaller-scale group projects made up an urban design project, but each group dealt with a more tangible and less complex area of study. This reduction in complexity allows more time and energy to be dedicated to spatial computing aspects.

The design task involved exploring local Urban Design ideas for the 'Southside' Business Improvement District (BID) in Birmingham. This was situated in an academically taught module. Three student project groups were formed from mixed levels and disciplines: MA Urban Design, MA Architecture, MA Landscape Architecture, and BA Architecture. A key stakeholder, the Southside BID manager, was involved to provide an initial context overview and feedback at progress review periods. Members of the public were also involved informally, as observed in the use of and interacting with the students, but not as named participants in this research.

Several key changes were made in the setup of the event, aiming to improve students' access to equipment, software, and understanding-skills development, as explained in more detail below. Improvements were made partly through event setup and research design choices, but also significantly by wider changing contexts.

Spatial computing was incorporated in key stages of the urban design process, as discussed in the following sections. These related to use of:

a. Virtual site analysis, was undertaken using Google Earth VR - (1 hour), compared to the desktop version and a real site visit as a means to understand the design project site: local site and context analysis
b. Public engagement using AR montage, supplemented non-digital methods with AR apps Augment and Thyng (3 hours) were compared to student developed methods equivalent non-digital methods, were explored in a live public participation exercise, to understand social perspectives, local stakeholder aims and objectives.
c. Transdisciplinary collaborative design was undertaken using Arkio VR, 3D design (three groups, each one hour, repeated over 3 weeks) software was used for transdisciplinary collaborative design, to develop conceptual ideas. Multiple users concurrently in VR headsets, each group working in shared VR space for 1 h each week, over 3 consecutive weeks, with self-guided design development in-between.

Virtual Site Analysis - Google Earth VR

Compared to use in previous 'Colab' (see 5.4), this event involved a greater number of students trying over less extended time, as a more self-directed exploration, each taking between 2-6 mins. This changed the nature of the outcomes towards the verification of the initial reaction. Compared to previous events, less time was used in their place analysis. This was due to different organisational conditions (more students, different pressure of tasks), rather than a pure research decision. Most of the participants had no or limited prior use of VR, even in unrelated software (games). The basic premise of exploring a virtual model of the site using VR was considered valuable by the majority, but not all participants. As previously mentioned, most were not able to fully articulate the precise benefit.

FIGURE 46 – SCREEN CAPTURE STUDENT INSIDE HEADSET VR

"You can't <u>even</u> get this in person!"

Immersion and Presence

All the participants indicated strong sense feeling like they were physically in the virtual place, describing the key features of the experience, as more real than desktop experience, e.g. *"It just feels like I'm actually there", "I feel like I can smell the food…even just the sound, it's weird, like I'm there but not". There was felt a level of enhanced clarity, "Feels more defined, different to desktop", "Much better than on a screen".* Most participants responded with enthusiastic vocalisation, indicating strong emotional impact: *"Oh my God… [Shriek] OMG, this is…", "Wow" (holding bubble to view street view), "That was so fun!", "OMG that is so cool… it's so fucking cool!", "Ooh wow that's sick actually.", "Pretend I'm Godzilla".* Though for a few participants the experience was less certain, potentially upsetting, describing it being *"trippy", "so high up"*, or *"hard to navigate".*

Difficulty with Controls (Controllers)

Many users found difficulty navigating the space due to the hardware interface, especially the hand controllers. This related to a sense of loss of control and uncertainty/disorientation, e.g. *"It's hard to navigate the system", "How do I move forward?, "I don't even know what I'm doing at the moment", "I can't tell the difference between the buttons", "Once you get used to it, it could be really cool"*

FIGURE 47 - SCREEN CAPTURE STUDENT INSIDE HEADSET VR

Spatial Perspective

Several participants described a sense of enhanced spatial capability and perspective, including in ways that went beyond the desktop version: *"It does feel like I'm in a drone", "When you are at the building roof level, you can see all the other streets around you", "Two sets of information at once", "It's a different perspective." And "You can't get this view at the street level", "Can't even get this in person".*

There were various broad, often lively statements alluding to a general feeling of being an engaging experience, with some slightly intangible benefit to their perception of the place, in a loose, broad sense. Several highlighted benefits to perception were beyond the capability of either a site visit/or using the desktop version, such as the ability to fly over and get a strategic perspective. As these visual positions are possible in the non-VR version, it might be that the immersive experience added a sense of emotive importance to these views.

All positive sentiments came with the caveat of various technical limitations, which again echoed those highlighted in the previous case, Co-Reality Brum: being, the lack of interaction or manipulation capability, and limited image resolution (Aerial and Streetview). Both technical limitations were equally present in the desktop mode, but participants indicated that this had a greater impact in VR. One participant, who had greater experience than many of the others, felt strongly that it had no effect on their understanding, but that this was not an issue inherent to VR as a mode, but the specific limitations of GE.VR which they felt was not making the most of VR capability.

As a spatial computing technology introduction, the simplicity and instant cognitive effect presented by G.E VR was useful in allowing new users to gain familiarity with VR generally as an experience. This was both in terms of a lighter emotional impact of cognitive immersion and simpler functions: to focus on the basics of how the interface and controllers are used. For facilitators (and researchers), this stage also indicated varying requirements for support and varying levels of engagement.

The previously stated potential barrier, for that makeup/headwear, was not repeated; in fact, several students wearing headscarves and makeup were the first to try, with no hesitation, or statements presenting an issue. Having a need to set up VR, and to show each other via a screen (initial limited number of headsets, space), and the specific locational setup requirements created an experience of static, individual, 'one-at-a-time', peer pressured performance.

Public engagement - AR montage

Over two sessions, the student groups were tasked with exploring potential methods for a public participation exercise and then using that method on-site, speaking to locals and visitors to the south. Students had the freedom to explore the methods they would use. While it was not the intention to review the students' methods as direct research in themselves, it was expected (and was the case) that gaps in the approach were in areas well understood in wider collaborative urban design practice and theory. However, the perception of methods as well as the actions undertaken were of interest to appreciate the underlying meaning for decisions and perceptions of spatial computing elements within the dynamic, exploratory case context.

The AR walk method, as developed in the prior research project Reimagning Southside (see- 7.4 RS-PP), was introduced in detail by the module lead, both in terms of its theoretical rationale towards a participatory process and as a principle working example for the use of AR: as a tested, working method. This included a switch to a fundamentally similar AR platform, Augment (2023) (from Thyng), to support cloud content sharing between devices, although Thyng was still used by one participant.

During a guided exploration of ideas for potential participation methods, it became clear that, as a collective, each project group had separately indicated appreciation of the potential for AR but lacked confidence in it as an effective solution and/or in their ability to use it. Several of the students communicated their perception (pre-conception) that AR was not sufficiently developed to be fully reliable, though this was strongly aligned with a reluctance to actually explore or test an AR approach to justify this view. Interestingly, they took the principle aim of an AR idea and developed their own interpretation of how to achieve it but not using AR directly, indicating that they saw the potential, but were not confident in either the current state of the technology, and/or their own ability/experience with it – the latter cause being also given by the module tutor in a follow-up reflection. Following their own exploration/decisions. I also set up and gave access for them to use mobile app 'Augment', with the files from prior public participation project Reimagining Southside, (though near to the event), one or two from each group seemed to take on exploring the AR app role.

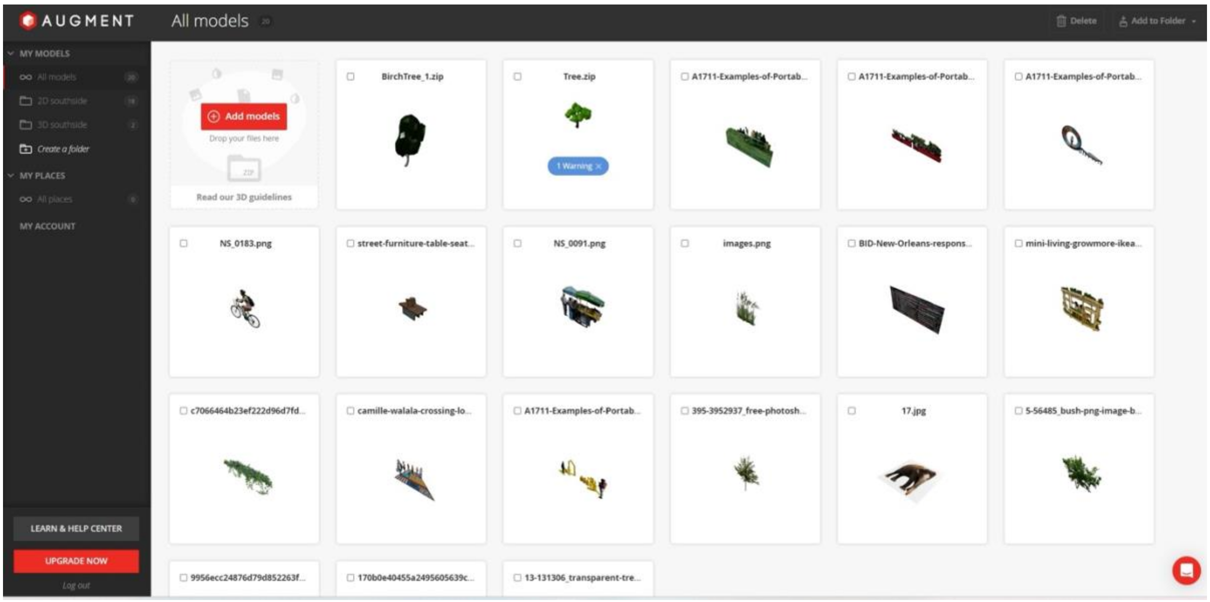


FIGURE 48 - LIBRARY GIVEN TO STUDENTS (AND AS USED IN 5.5), WITH AR SOFTWARE AUGMENT: AR VIEWER (AUGMENT, 2023)

Each group felt that a physical interactive object was preferable when interacting with the public and developed physical activity as the primary method. The concern was largely that the iPad would be mistaken for a questionnaire based 'survey', which they saw as an overused-unengaging method that people would avoid engaging with. These views were presented following approximately 30 minutes of discussion, before undertaking any extensive testing of the software, or the 'AR walk' methods as presented, but rather were derived from group workshops, thinking through the complexities of engaging with members of the public (via mind-mapping exercise).

The tutor encouraged the students to try the AR method alongside their preferred method. The AR method was provided, as setup via Augment, with a range of 2D and 3D files (as RS-PP), as well as introductory guidance on how to use it on personal mobile devices.

The three mixed discipline groups used a combination of a method they had developed alongside the AR app on personal mobile devices. Despite reservations about technology, the main methods they developed were in-fact quite closely aligned to and had interpreted aspects of 'AR-like' capability, or could be implemented as AR(/MR) based system:

- Group A used a 2D map, where pins could be added to indicate desired types of design elements
- Group B created a 3D model where representative colours could be added to indicate desired types of design elements
- Group C Used a transparent acrylic screen, which users could draw over the top of

For most students, this was their first experience with participatory activities. It was stated and observed that there was an initial nervousness, later stated by some on reflection, due to concern over their level of skill with public engagement.

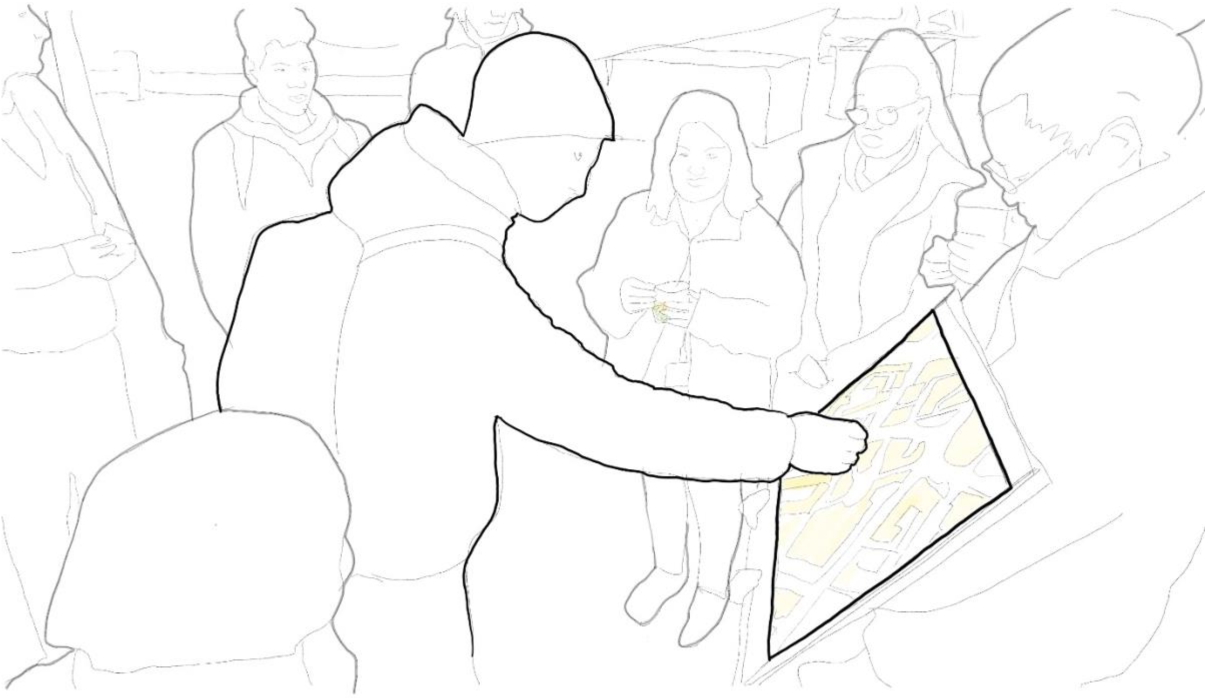


FIGURE 49 - GROUP A: MAP-PIN METHOD

FIGURE 50 - GROUP B: MODEL + PRECEDENTS

The method developed by Group C, was akin to an analogue version of 'AR drawing', visual augmentation, where one can draw over space (though not in 3D).

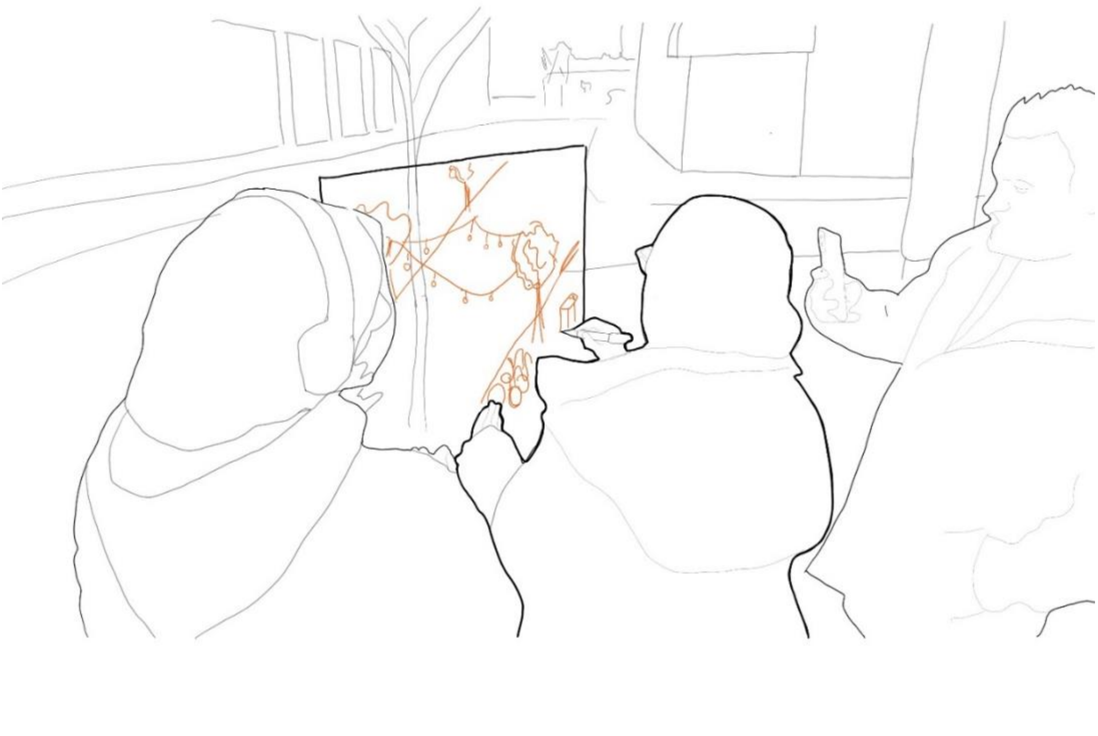


FIGURE 51 - GROUP C: ACRYLIC SCREEN + PEN

FIGURE 52 - GROUP B: USING AR, TAKING INSTRUCTION, DISCUSSION WITH MEMBER OF PUBLIC

FIGURE 53 - AUGMENTED STREET TREES, USING AUGMENT AND PHOTOGRAPHIC CUTOUTS

Usability

Participants felt that AR had considerable promise in terms of engagement and ability to interact with the scene. However, they identified issues with fluidity or complication of user experience, which one user described a "Janky". Issues also emerged from technical inconsistencies, such as object placement. This was influenced by onsite environmental conditions like brightness of outdoor light, rain and wind (movement). Several of the students had the perception (pre-conception) that AR was not developed enough to be fully reliable, although this was strongly aligned with a reluctance to explore or test an AR approach to justify this view. The experience contrasted significantly in comparison to the traditional methods (pins, stickers, physical models). The immediate and reliable interaction of traditional methods presented fewer technical challenges, but lacked the dynamic visually compelling, interactive experience of AR. This highlights a need to balance sophistication with accessibility.

Engagement and Discussion

AR allowed participants to see, interact and change virtual elements directly, which stimulated and enthusiastic response. This was especially the case for members of the community interacting with students, who found the approach engaging and visually appealing. Showing the AR method to a local resident who had been engaging in the student activity, they stated, *"around the Tapoki restaurant, Yangard supermarket & Urban Kitchen… it needs more greenery - more street trees*". On seeing this happen live, they concluded that the AR method was the most useful, as they could see the ideas immediately. It helped them not just to articulate what they wanted, but to get an immediate sense of the change, to confirm the choice and meaning, and for them to select their specific view and purpose.

Though used in a more limited capacity, the AR approach showed great potential to start a user guided, nuanced and reflective discussion, through the direct and interactive visualisation. For example, in discussing proposals for symbolic gates, or public art, group A had created a model of an early concept 'Gateway' design and uploaded it into to app for viewing on site. Showing this to a small group of the public, the student was very surprised with the immediately, highly negative reaction to their proposal. Their proposal, being a symbolic structure, had opened up areas of political debate on the nature of 'China town' – i.e. where the mix of residents is of a much broader 'Asian' influence than the name suggests. In this context, seeing the proposal in a direct visual way immediately revealed how much the members of the public were against the idea. For the student designers, this also presented a very useful experience for reflection on their approach and design process. However, the more traditional approaches used by students did offer quicker, simple ways to promote user thoughts, but these were generally broader and more descriptive of 'items wanted' (a controlled narrative), rather than promoting deeper reflection from members of the public.

Confidence and Adoption

Confidence varied for students using AR. There was a general perception of technical limitations and complexity which led all groups and most individuals within to dismiss the approach prematurely. The groups strongly favouring more traditional approaches; drawing, or pinning/placing codes to a plan or model. Despite this, the groups took the principal aims of an AR idea and developed their own interpretation of how to achieve it but not using AR directly. This indicates that they saw the potential but were not confident in either the current state of the technology, and/or their own ability/experience with it – the latter cause being also given by the module tutor in a follow-up reflection. This highlights the need for AR to overcome users' unfamiliarity, through greater exposure and training, and to focus on making interfaces as reliable and accessible to use as possible.

Digital AR elements were included by two of the groups, but they were very much used as a side method, testing as a quick comparison, and/or supporting the main methods. It was also undertaken by only one or two group members. In all the cases digital AR was used, this relied exclusively on the use of the previously established method from the 'AR walk' project, without further exploration and for which the guidance and files had introduced and shared. Following their own exploration/decisions. I set up and gave access for them to use mobile app' Augment, with the files from prior public participation project Reimagining Southside, (though near to the event), one or two from each group seemed to take on exploring the AR app role. This limited exploration of AR from the student groups, followed a lack of confidence and a tendency to default to familiar and perceived to be simpler solutions. However, in conclusion and following real experience with the AR system, several students recognised and reflected that it was far less complex than had been initially perceived and that their consideration was limited.

Representing Design Ideas, Space and Context

Participants were able to assess symbolic and representational meaning of their design. While their initial approach was to produce a realised design idea, their reflective process developed towards a more participatory understanding, or at least a reflection on how their ideas may have been naive to political views. After a member of the public immediately and forcefully rebutting the student's highly finalised but non-participatory proposal, the following design development process incorporated deeper reflection on a wider spectrum of beliefs that might potentially influence the perception of design. This moved beyond initial preconceptions. As previously discussed, the visual effect of the AR approach emphasised an immediate end-user feedback, which opens questions the ideal level of realism used and how this relates to stages of the design process.

FIGURE 54 - STUDENTS OUTPUT GROUP A – MAPPED PINS & AR

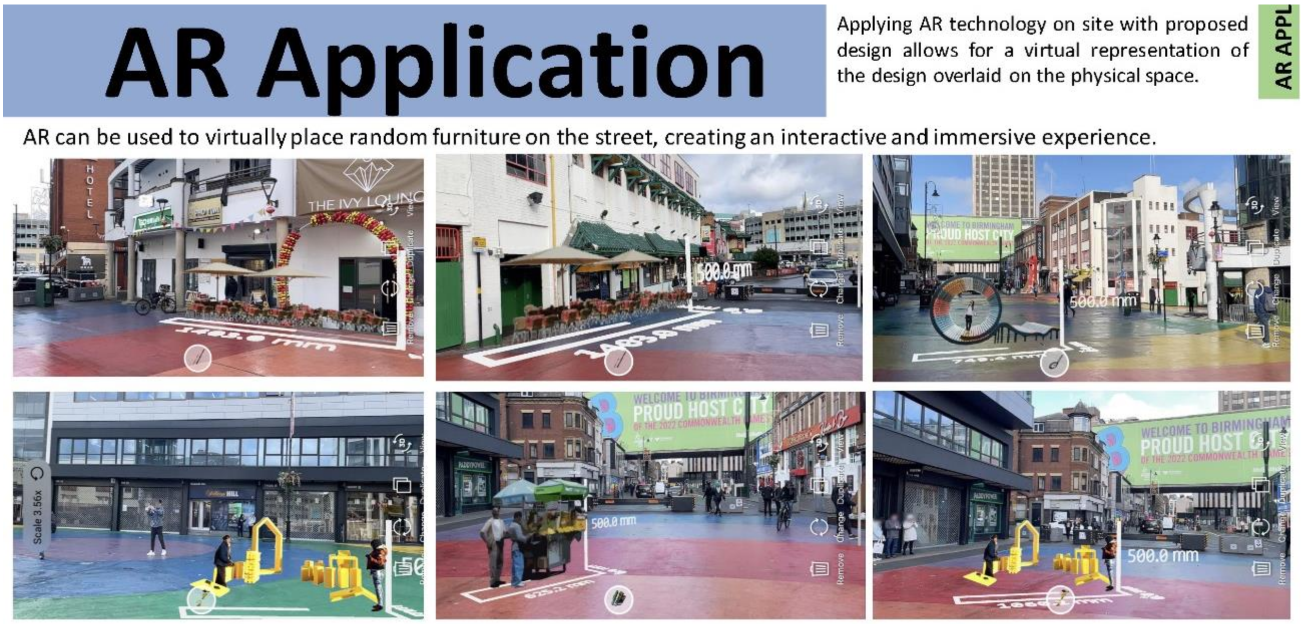


FIGURE 55 – STUDENTS OUTPUT GROUP A – AUGMENTED REALITY MODELS AND IMAGES

Figure 56 – Students Output Group B - 3D Model, Movable Elements & AR

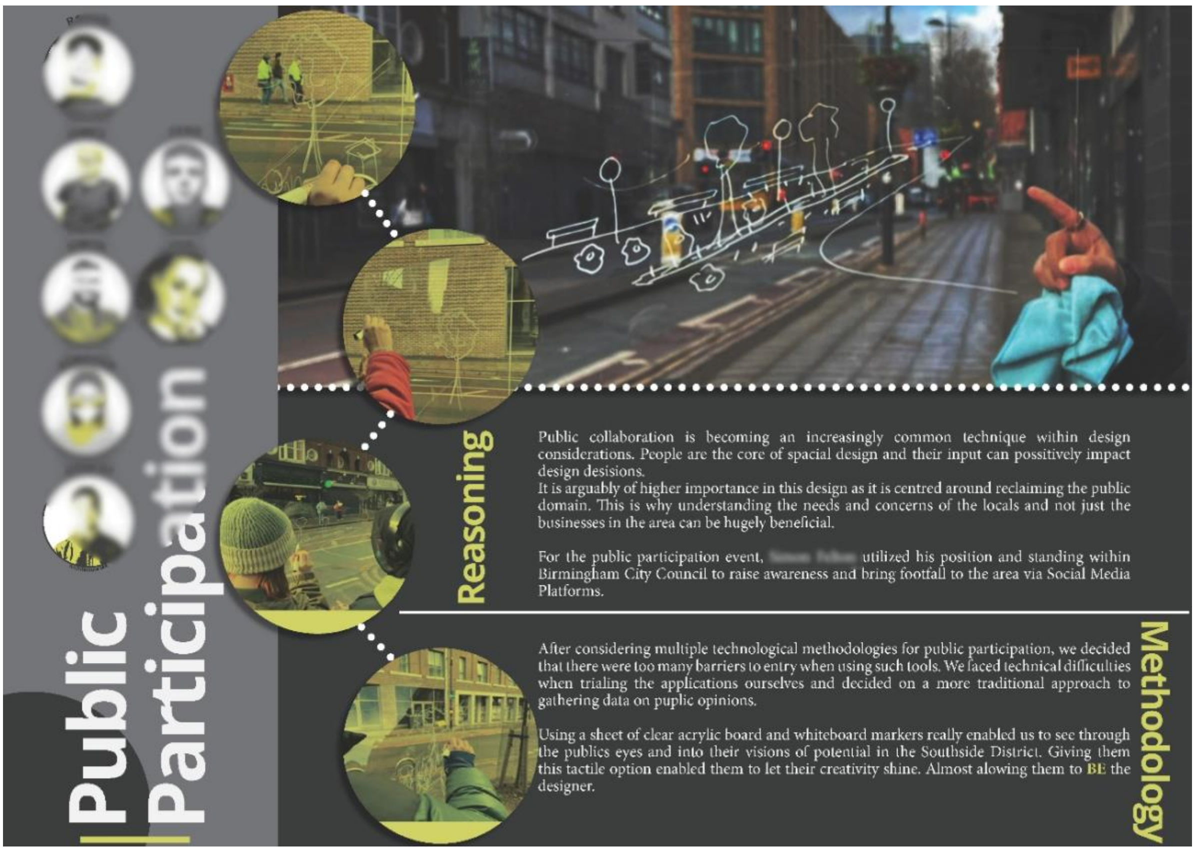


FIGURE 57 - STUDENTS OUTPUT GROUP C – AUGMENTED DRAWING - TRANSPARENT SCREEN/ PEN

Comparison of groups methods

The student groups felt that the mapped pin method was most successful/engaging, though this seemed to be judged primarily on numbers, as having most members of the public engaged. However, this result was likely much more to do with the location within the main central square, vs the less active surrounding streets where the other groups were located.

The main tutor felt that whilst the methods of Groups A and B did give a benefit of allowing holistic listing of potential desirables design additions, the placing of these on a map/ 3d model, presented a great limitation in ability to map elements which are not single position objects (e.g . a cycle route), or entities which are of one location, and lack depth, composition or much appreciation of meaning.

Transdisciplinary Collaborative Design - Arkio

New facilities at Birmingham City University (STEAMhouse, 2024) opened the opportunity for this event to be hosted in a dedicated co-working space with staff and technical resources (Meta Quest 1, 2 mobile VR headsets, spare batteries, dedicated AC Wi-Fi router, and large 2D screen) to facilitate collaborative spatial computing. Furthermore, for the software, Arkio was chosen as the most aligned with the collaborative aims of the research. At the start of this research project in 2019, it was an early beta but had emerged as a fully stable commercial release in line with the timing of this event. The use and testing in this event were supported by Arkio with an educator licence, which allowed full access to all capabilities, including the networking capability required for multi-user (co-design) and sharing files more easily between users and the software interface using cloud hosting. Together, these significant context changes facilitated the ability to set up a collaborative design process in VR. With the space and equipment resources described, it was possible to host up to six users joining the same VR space at one time.

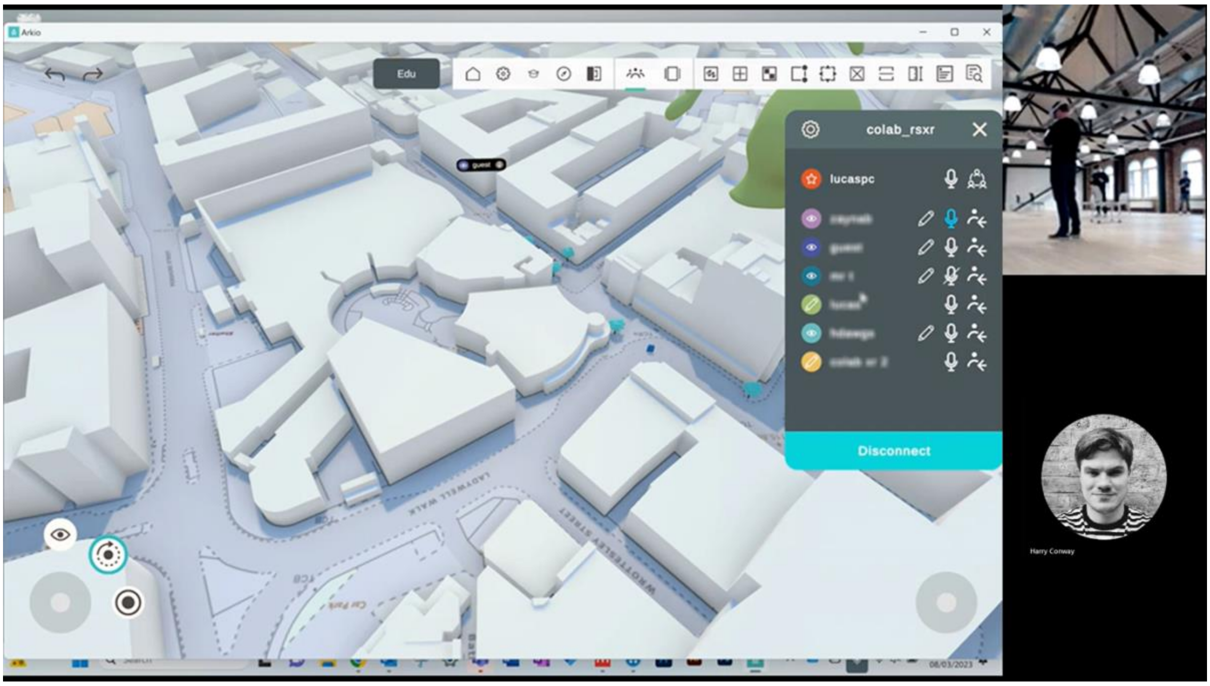


FIGURE 58 - TOPOGRAPHICAL/BUILDING HEIGHT MODEL IMPORT, ARKIO MULTI-USER ENVIRONMENT

In line with this improved access, via a more dedicated setup, an extended timeframe was allocated for participants for familiarisation with the specific hardware/software combination and for using VR in the design process. Three groups of six participants were each afforded 1 h each week, which was repeated over three consecutive weeks. This aimed for a less pressured initial session, encouraging exploration (play) with the tools and capability, and following sessions for starting to apply and experiment with the design tasks.

Models were downloaded and collated to form a base 3D model from the Digi map OS Building Height and Topography of the Southside project area, combined in Rhino, and imported into Arkio as a layer. Initially, this was not positioned as a fixed element in Arkio, although later was to prevent editing of the base layer.

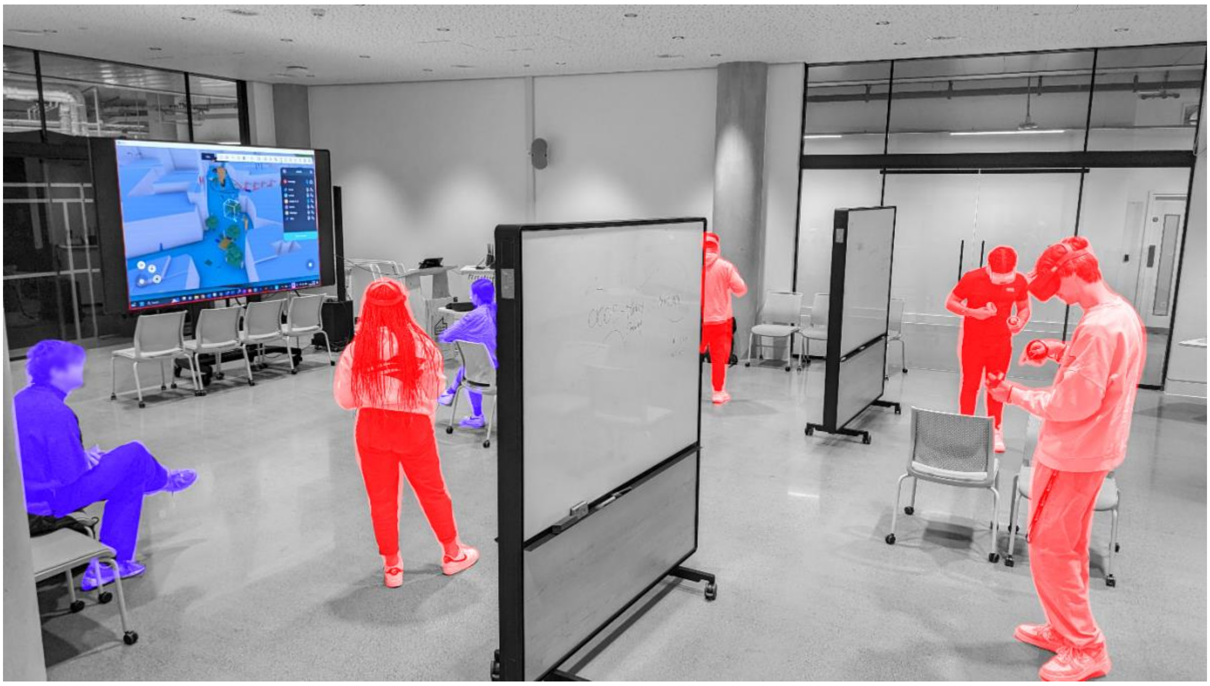


FIGURE 59 – COLLABORATIVE ROOM SETUP, PARTICIPANTS INSIDE (RED) AND OUTSIDE (BLUE) HEADSETS, SHARED VIEW ON LARGE 2D SCREEN, MODEL SPACE PROJECTED FROM DESKTOP

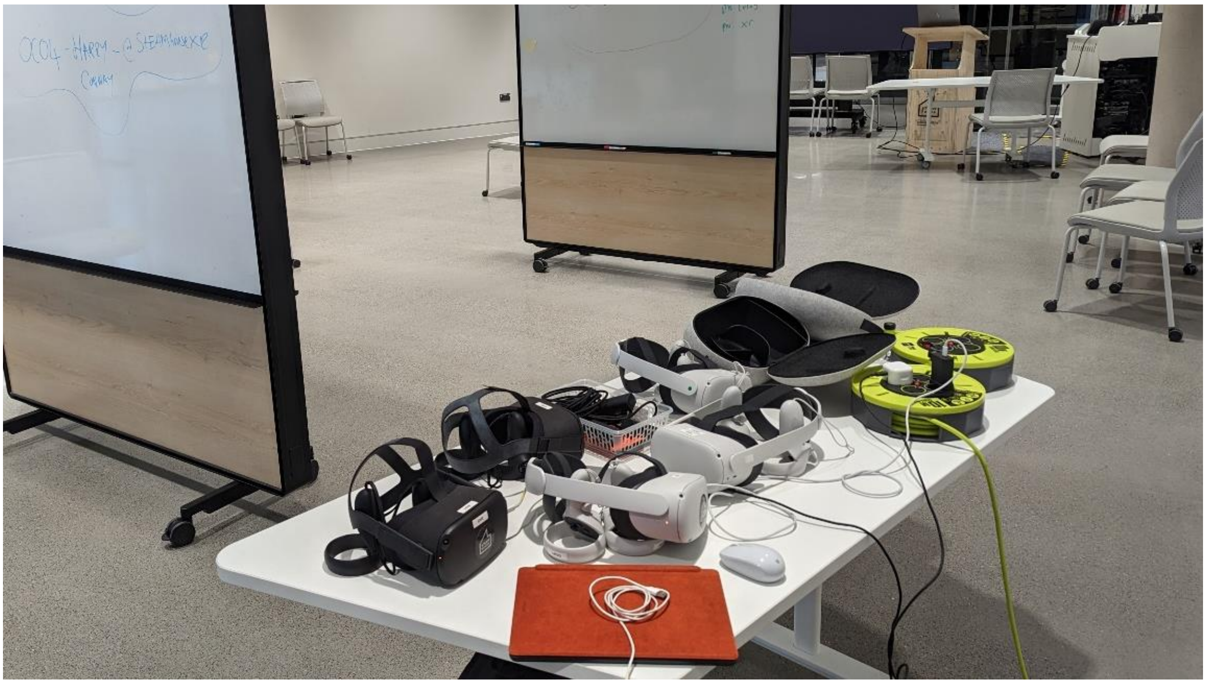


FIGURE 60 – COMPLEX SETUP: ARRAY OF HEADSETS, CHARGING, ADDITIONAL BATTERIES, SHARED SCREEN, SPECIALIST ROUTER, PASSWORD AND USER CUBICLE ROOM ARRANGEMENTS - SESSION 2

Usability and Learning curve

There was a learning curve for both participants and the researcher/ and technical expert (as event facilitators). The first session was useful to explore the interface, capabilities. Technical difficulties were a regular part of the experience, but there were also moments of progress, learning and excitement, especially as participants started to better learn the system and experience the shared immersive environment. Three sessions were required to acquire a basic understanding of what was for many, quite a different system, and then start to explore design ideas and develop familiarisation.

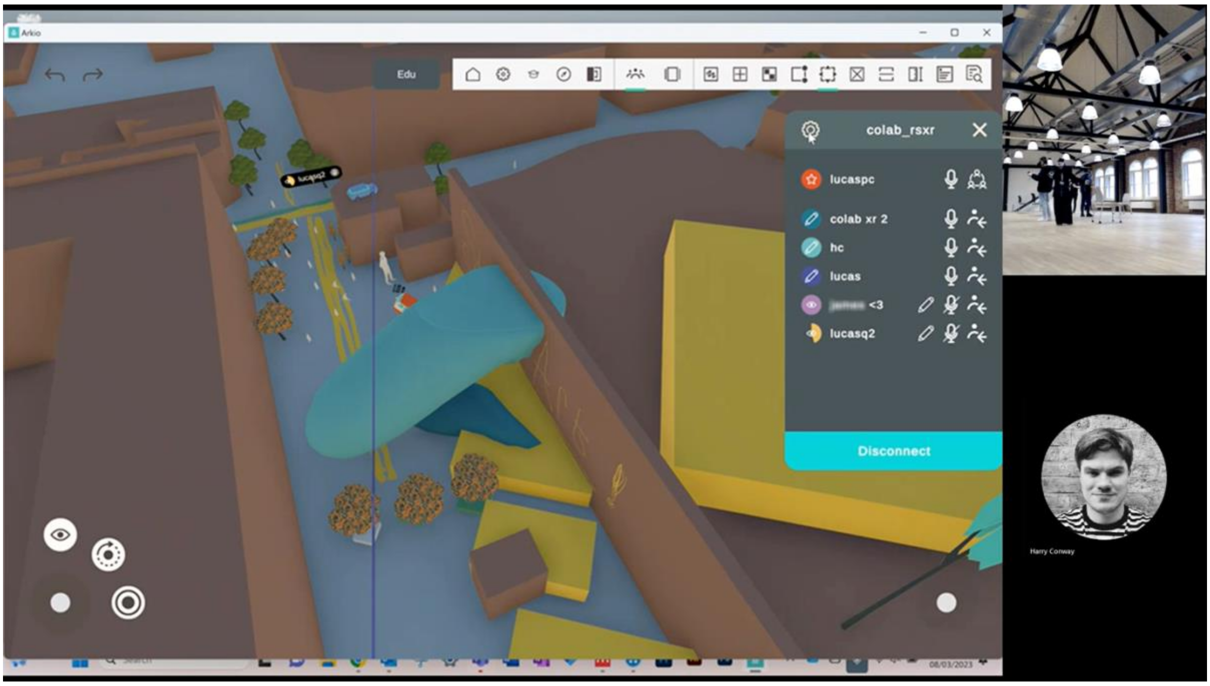


FIGURE 61 - SESSION 1: DESIGN COMING FROM PLAYFUL PROCESS, INCLUDING ACCIDENTAL CHANGES, SUCH AS CHANGING BUILDING AND SURFACE COLOURS

License - For the first group there was a key initial issue of users being removed from the virtual collaborative space. This was due to an initial facilitator's misunderstanding of how the Arkio meeting system worked and how the setup of the educational license interacted with this: one license with guests invited, rather than licence to be added on each device. Whilst this was resolved within the first hour, it may have given some of these participants an initial negative impression of stability.

Audio - Specific technical difficulties were reported regularly by all participants, including reoccurring issues with correctly logging into the devices, in addition to multiuser licensing to setup. From the devices, audio and tracking issues prevailed. There were also significant challenges with audio management, which resulted in a lack of ability to communicate effectively, due to echo and feedback from various devices. There were mismatched volume levels, creating an overlapping cacophony from the various headsets and PCs. The correct setup required much guesswork between the various devices, which then also varied between the live conditions and acoustics in each different event spaces (between session 1 and 2-3). Audio issues added to distraction and missed communication, reducing ongoing understanding between users.

Visual - Participants also experienced visual issues, from rare and extreme to common and regular. For example, one user experienced a total malfunction, where the whole virtual world flipped around, lenses showed different images. Many more users experienced tracking and boundary glitches across the series of sessions.

Interactions - On reflection, one participant was particularly critical, described the system as clunky and suffering usability issues - *"Sketchup does this much better",* a much more established 3D software. They felt that the lack of absolute precision impacted on the fluidity of design process, as the brush tool was felt too small and general snapping was inconsistent, making it difficult to draw straight lines and position objects accurately and smoothly. This was exacerbated with an imported model, which did not share the same snapping function as those created in the software: it needed to be either imported as entirely fixed to a reference surface plane, or entirely floating and unable to fix to other objects. Most participants were more forgiving of the same issues, for example, "With better snapping, this would be really intuitive!". "This could be really useful when it's smoother."

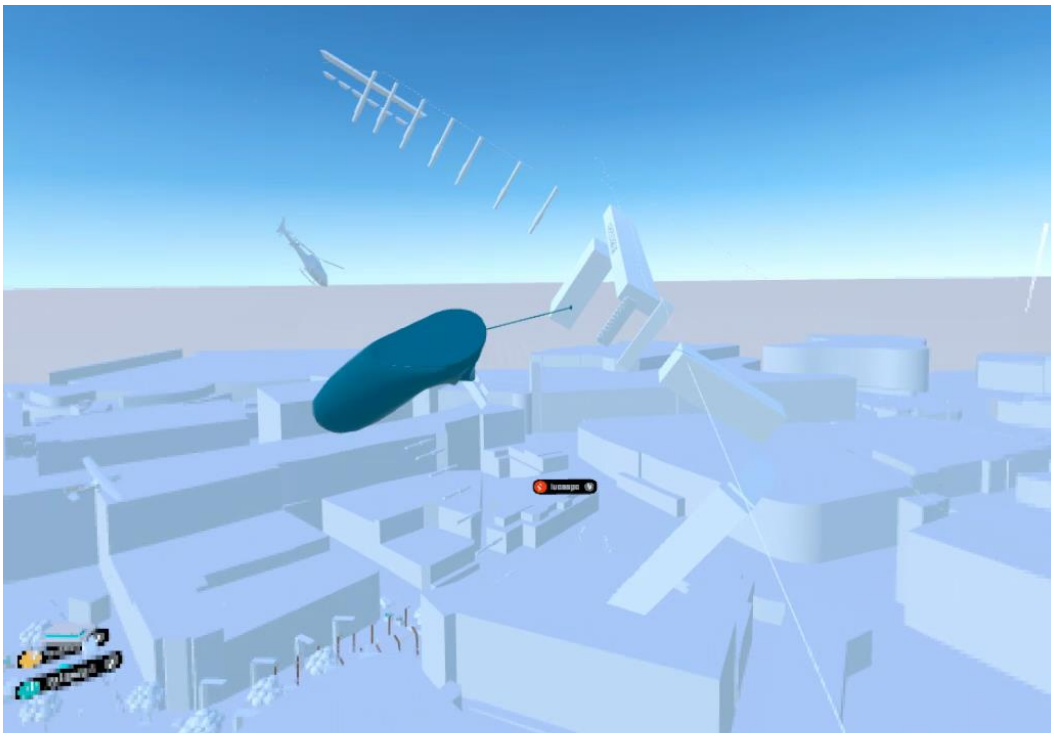


FIGURE 62 - PARTICIPANTS COULD NOT EASILY PLACE AND SNAP IMPORTED MODEL ELEMENTS TO EXISTING, HERE INITIALLY FLOATING AT EXTREME ANGLE.

Familiarity – as time went on, the direct first-hand experiences with Arkio and the Quest (1, 2) headsets allowed participants to better appreciate and navigate areas of success and design improvement more easily. Prior experience and preconceptions also appeared to influence the level of acceptance and engagement at various stages. It took until final stages for some time to appreciate the fact that the exploration of SC was part of the activity. By the end, almost all participants had become more confident collaborating in the shared VR space, aligned to familiarity with the situation and controls, but equally in tandem with understanding the aims of the project. This was evident in the relative completeness of the overall models and, in some cases, refinement in design detail.

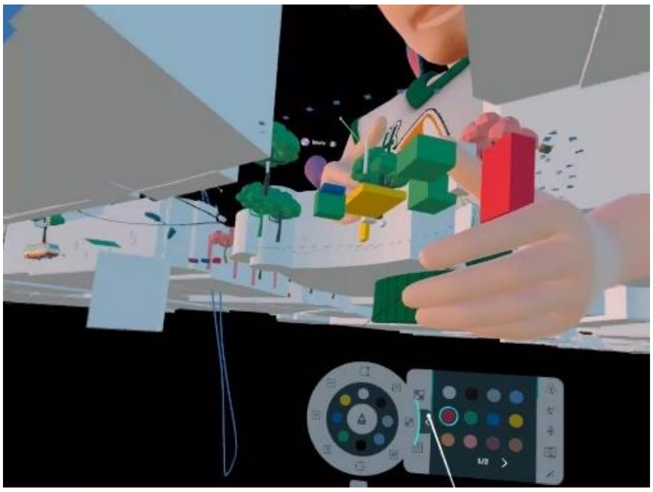


FIGURE 64 - USER STUCK UNDER THE FLOOR PLANE

FIGURE 63 - BY SESSION 3, PARTICIPANTS HAD DEVELOPED INCREASINGLY SOPHISTICATED DESIGN MODELS

Collaborative Design Process & Social Dynamic

Collaborative Design Process was encouraging, and improved for most as time went on. Full collaborative working did not fully start to function until 2nd Arkio session for two of the groups and 3rd session for one group. The final session, for all, showed a greater range of interactions and focused on collaborative/social dynamics. Whilst most started off in silos, by the third session there was much more interaction within the virtual space, with several participants interacting with each other to complete design tasks, either by direct action or in conversation.

Many participants showed and expressed a developing confidence in the use of VR (Arkio) for design, especially for use at the human scale and for two of the three groups, an emerging collaborative workflow.

For one group, the general feeling was less positive overall, though varying by members. They were struggling with deeper social/collaboration issues and felt that the addition of VR sessions reduced their progress, though this was largely due to it being an additional new skill / technology. This was not without some specific criticism of the software/hardware, but was also a more general critique of 'digital' means, where in-person was felt to be more productive. For all, the social dynamics of the group had a large influence on the ability to navigate technical challenges, as a general build-up of positive or negative attitudes. For individuals, those less familiar with VR, or gaming, and felt under some social pressure, were less engaged with this new approach.

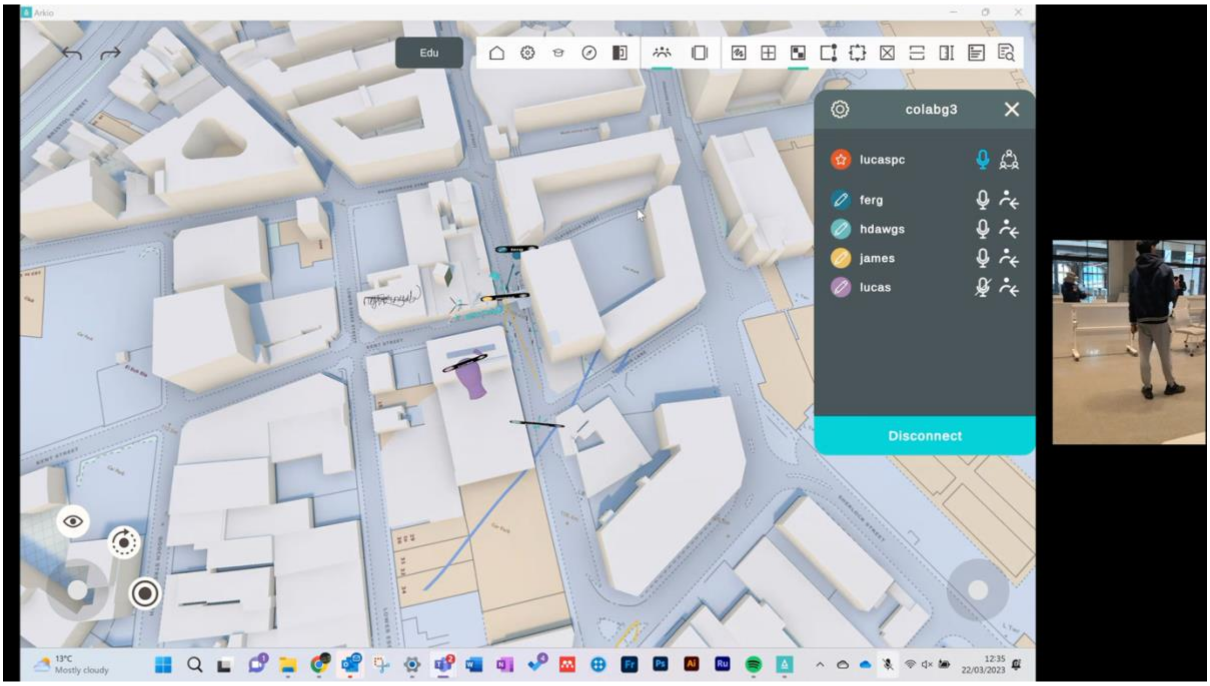


FIGURE 65 - USERS HAD TO CONSIDER HOW TO POSITION AND INTERACT WITHIN THE VIRTUAL DESIGN SPACE

Immersion, Interaction – in real and virtual spaces

For all groups, VR and to some extent the setup in space had somewhat segregated their VR active and Real; non-active users, though communication between those 'in' and 'out' of VR varied by group and overall collegiate success. Those outside could not easily spatially interact or even see the view/interaction of those inside, breaking collaboration somewhat: as those outside of VR were excluded from fully appreciating what was being done. These participants could have joined via their laptops but chose not to.

Immersion was not enough to prevent issues of disconnect in spatial awareness, as numerous accounts of issues related to lack of adherence to personal space and avatars blocking views or creating chaotic interactions with multiple users and when users were scaled out (i.e. 1:1000) making avatars very large). For example, *"Someone just punched me in the head!"* (virtually, not literally), and *"People's faces and controllers* *keep getting in the way".* Despite frustrations, engagement was high for much of the time. Users generally reported on the potential and were able to design and problem solve effectively.

FIGURE 66 - USERS AVATARS CHANGE IN SCALE, AND OFTEN GOT IN THE WAY OF VIEWS

Engagement, Creativity & Playfulness

Students were able to give a tour of their design and explain it as we moved around the space. Relying on student confidence also, for example, the two subject aligned masters students (from urban design, landscape architecture), where much more confident. However, there was a playful element to much the creation process, with multiple instances of joking around, such as placing elements in comedic situations. In the capacity of the reviewer, the ability to freely roam their design space, allowed to see a part of the process a tutor may not always be able to see, as something would not normally shown to perceived in a position of authority or formality.

FIGURE 67 – COMEDIC SCENE FROM COLLABORATIVE DESIGN IN ARKIO – PERSON SITTING ON A TOILET, OTHER WITH A SINK & PLANT ON BODY

Facilitation, Setup & Implementation

The way new SC technology was incorporated played an important role. Testing the technical and considerations of organisational - contextual setup and capability was very important and was complex beyond initial expectations. Considerations required a combination of technical and social facilitation to increase the effectiveness of collaborative processes. However, SC was far from presenting a holistic solution that could be applied across the whole project but allowed specific applications that had some use at the different stages, though each with limits in capability that needed support from other multi-functional methods, such as in-person meetings, verbal presentations, sketching and mixed-media portfolio production. Within the wider process, considerations around which approach, as well as technical (hardware and software) choices to use at each stage were also still quite limited and compromised.

FIGURE 68 - STUDENTS STILL UNDERTAKING SKETCH IDEATION TO SUPPLEMENT VR CO-DESIGN IN ARKIO

5.7 Results Overall Summary

Spatial computing presented a range of new opportunities, some of which were tested and experienced, whereas others were still far off and discussed conceptually. Interviews provided a summarised account from highly experienced participants from design practice and software development teams, providing contextualised analytical comments. Live testing engaged students and the public at various stages of design learning with specific context-based desirables and appreciation. Across the data, there was a general success in functional, collaborative delivery of various SC types and methods, an achievement which may not have been at all possible only a few years ago, let alone with limited resources. Within this success, and even for the most established areas of SC, users consistently experienced a range of minor technical issues, for which complex considerations needed to be made to facilitate smooth setup and running. These technical challenges conflated and became more apparent as the context of use (events/projects) became more complex.

Consideration was needed in various ways across varying participant types, design aims, and along a spectrum from sensory: audio-visual, to organisational, human-interface design areas, at large and small scales of delivery. Technical considerations presented a limit in themselves, in that issues or lack of scope halted further appreciation of a deeper understanding of SC's potential impact. This is especially the case to deeply appreciate the potential social, systematic requirements on design, planning processes, and beyond. The results come from testing in conditions that were not 'perfect', but aligned to real-world use cases: with interest in the uniquely complex and variable conditions in which people normally undertake Urban Design work, for example:

- Under pressure, with financial constraints, with influence from organisational conditions, under social or political power structures, influenced by personal capabilities, biases, and group dynamic.
- With focus on design first, not the technology (SC): for urban design, from considerations of architecture, planning, social science, economics, etc., of making better places, via understanding ever-changing social and physical urban conditions.

The way new SC technology is incorporated plays an important role. Using more direct first-hand experiences with SC allowed participants to appreciate and navigate areas of success and improvement more easily. However, the social dynamics of the group had a large influence on the ability to navigate technical challenges, as a general build-up of positive or negative attitudes. When experiencing negative effects of SC compounded negative wider design experiences and/or group dynamic. This was especially the case for those less experienced in urban design, and/or less familiar with SC. The additional shift in approach from more established tools was more challenging. Considering which approach, the technology type at each stage was critical to building confidence from those less familiar. Testing the technical and contextual setup and capability was very important and found to be complex beyond initial expectations. Considerations required a combination of technical and social facilitation to increase the effectiveness of collaborative processes. These factors will be reflected on more deeply with relation to existing knowledge in Chapter 6 - Discussion, to follow.

Software Choices, Limitations, Validity

Early in the research, a survey of various types of AR and VR software was conducted. This review considered the type of software, stability, and suitability to the needs of collaborative and participatory public engagement. This revealed several options that can be utilised, each had specific limitations that needed to be considered in context (aims, collaborative makeup), with relation to resources (hardware, support). There was a compromise between being simple to use - but limited; and sophisticated - but complex. The software eventually chosen had some balance between accessibility and capability, related to the following resources, across the project timeline- see table 16 below.

TABLE 17 - RESOURCES AND TECHNOLOGIES USED ALONG PROJECT TIMELINE

Stage	*Space*	*Hardware*
5.3 2021-2022 Testing/ 5.4 Colab (CRB)	Online MS Teams (Covid 19) Teaching Studios, MS Teams	1x Oculus Quest 1, Oculus Rift S and Alienware r17 laptop 2019, Google Pixel 6 mobile phone
5.5 RSS 2022	On site – Southside Public Realm	hired iPads, Mobile phones, various Android/Apple devices
5.6 Colab (RSS) 2022	Teaching Studios Steamhouse, dedicated open spaces	CRSS: Mobile devices Apple iPhone, various Android devices Oculus Rift S – Google Earth VR Oculus/Meta Quest 1/2, Pro (testing only)

For example, Google Earth VR presented an easy way to get a highly immersive VR experience, though lacked much in terms of interaction. Arkio was chosen as it has considered a similar balance, with simplified range of key interactive capabilities, alongside some collaborative management and is designed and built to run across mobile and desktop platforms, including mobile tablets/headsets, they are limited by design, with low-poly geometry and basic rendering to allow stability. Even then, it presented various limitations inherent to the platform and early nature of its software development.

Recurring Technical Issues

Across live events, participants experienced and reflected on various technical issues broadly and specifically.

The following key issues persist for AR and VR technologies, with some overlap.

AR

- Ability of users to correctly see AR outdoors, impacted by screen quality, especially brightness and weather conditions. Tracking and calibration ability of software, similarly, with addition to due to greater extremes of lighting, people moving around, even wind (moving things), which varied greatly by position and the equipment used (iPads vs. various mobile devices).
- Screen size limitation, weight to size compromise
- Very limited precision for placement and manipulation of objects in 3d space via 2d screen and finger manipulation, especially holding the device with one hand, effects positioning, scaling of objects, and depth perception

VR

- Boundary, regularly dropping out, sometimes not loading correctly – consideration of digital and physical space. 1 device completely stopped working, issue of one screen (eye being inverted) – became unusable
- Audio levels (management), especially for collaboration, in mixed environments often result in cacophony, misunderstanding, and likely reduced communication. This was improved by manually setting each device (though imprecise). This also took time away from the design process/attention from facilitators.
- Limited battery life, for multiple repeat use of power intensive apps, 3d Collaborative environment. External battery packs were used for extended sessions, although additional management/investment (charging those beforehand, etc.) was added.
- Debate around the need for and implementation of avatars. In the shared design space (in Arkio), they were often getting in the way, especially when larger. The way they are aligned to accounts; in this setting, they were not avatars of the people actually using them, so users could not identify each other quickly or at all. In the context of multiple new users, needing flexibility and having time limits, setting up multiple avatars and logging into different accounts would be totally infeasible.
- It has technical capability for precision but lacks numerical dimensioning or highly accurate snapping (in the software tested).
- Vision, setup of inter-pupillary distance (IPD), and headset position on the head caused visual blur.

Ecological Validity of SC types used

An appraisal of the SC types used against the criteria (adapted from 'EVAC' (Joseph, Browning and Jiang, 2020; Krukar and Schultz, 2024)); the study makes clear how the ecological validity is pertinent to qualitative, exploratory studies, as called for in recent research (see 3.1), though some limitations remain (see 6.4).

TABLE 18 - ASSESSMENT OF ECOLOGICAL VALIDITY OF SOFTWARE USED

Ecological Validity ('EVAC' dimensions)	Site Visit - Google Earth VR (3D mapping)	Design overlay - Augment/Thyng (AR photo)	Co-Design - Arkio (VR 3D)
Stimulus fidelity	Photorealistic satellite imagery, though lacks ultimate detail, static, Geometry lacks precision (lidar scans, variable by location)	Photos, high detail: do not visually blend into scene, only overlay, could have shadows	Low-poly, stylised; stable on various hardware with different interfaces (VR headset vs tablet)
Sensory richness	Visual only, no sound, or other senses	Ambient sound from site, overlay is silent	Hand interactions - currently lacking some Kinaesthetic senses, collaborative audio only (with nuance issues) _ variable quality
Behavioural freedom	Teleport + fly around, cannot walk around 360 view only (in 'Streetview'); cannot manipulate environment or add design entities objects.	Walking freedom, lacks annotation, cannot reach or grab other than imported objects	Object manipulation is palette like. VR close to design drafting, but real-world 'construction like' lacking various affordance nuance. AR lacks spatial manipulation
Contextual embedding	Neighbourhoods can be seen, lacks life up close, depends on date of aerial mapping. May be quite historic elements	Rich, live on-site, reality is backdrop	Depends on level of imported model, limitation by multi-device capability. Integrated maps lack detail (Open Street Map, OSM)

6 DISCUSSION: CONSIDERATIONS FOR A SPATIAL FUTURE

The following chapter discusses key themes in relation to the research questions and objectives with relation to existing knowledge on spatial computing (SC) for Collaborative (Co.) Urban Design (UD) (as 'SC-CoUD'), as outlined in Chapter 2, and with relation to contemporary themes and gaps outlined in Chapter 5. The following three sub-chapters evaluate the influences of SC relating to 3 research questions. Themes were formed via holistic evaluation of data, which have emerged across the entire timeline of events (see 4.1) and philosophical basis 3.

6.1 Q1. Capabilities: Alignment with Collaborative Urban Design Activities

Capabilities

Objective 1a: Assess current technical and conceptual capabilities of SC types

Adaptable - Devices, formats

Within the collaborative, transdisciplinary, and changing contexts, many different devices, systems, and formats were used and needed consideration of translation between them. The results presented an ongoing need for adaptable solutions (affordable, technically accessible), which enable consistent functionality and performance across a broad range of devices, platforms, and situations (Fonseca *et al.*, 2014). Aligned to this is the need for more seamless workflow (Horvat *et al.*, 2022) into, through, and out of SC without loss of integrity.

Incompatibilities presented fundamental institutional and/or individual barriers (see 6.2 b) due to particular systems and organisational requirements, reducing ease of adoption (see 6.2 a) (Delgado, Oyedele, Demian, *et al.*, 2020). Specialist (expensive) equipment and software can be incompatible with organisational set-up (for example, IT systems, networking), or changeable social and professional conditions that can demand quick adaptation of the approach. Largely, this was understood as an issue of these new systems being supported (trusted). This relates to a need for widespread adoption, which would embed systems, reducing the requirement for specific organisational setup (Parjanen, 2012).

Development and modelling processes require the handling of different 3D file types. Different formats are required moving between urban design affiliated 3d modelling software and those of game design.

However, this was facilitated greatly by recent plugins which reduced issues and provided much more integrated processes, closing the gap presented by Fonseca *et al.* (2014). This translation enabled file type compatibility, including easy transfer (import – export) of files, as 'data exchange standard' (Delgado, Oyedele, Demian, *et al.*, 2020). Some ongoing, more minor issues were still presented, due to different file type capabilities, resulting in a lack of, or misaligned textures, or loss of metadata. This indicates an ongoing need for deeper translation, and especially translation between the often-higher geometry/texture detail UD/Architectural software between (into/out of) SC software (live rendered game engine based), to facilitate more efficient rendering.

Format translation was recognised by software developers interviewed as fundamental in their contemporary software design approaches, acknowledging it as a well-understood/experienced issue of prior years. Each had ways to simplify this process and had multiplatform integration as a key functionality to simplify integration, including across SC and mobile operating systems (Torres Vega *et al.*, 2020).

The live events presented a generally effective navigation format, such as moving from Rhino to Arkio via a plugin. Some specific knowledge of the systems was needed, taking some time and focus from more experienced participants (i.e. post-graduate students, technical specialist professionals). Professionals and design students seemed very familiar with the issue and could collectively account for potential issues more easily (as a mainstream 3D issue, not just SC). This technical side of import/export was not tested here with members of the public; we might expect a much broader barrier, benefiting technical expert support.

Technical Performance, stability

In live testing, both AR and VR saw regular and repeated technical issues. Participants described the use of both AR and VR with words like 'clunky, glitchy, janky, hard, and complicated. Professionals reflected on experiencing general unreliability and/or indicated specific examples of technical issues which made the use of SC unreliable. It has not been possible to accurately compare levels of impact in such variable contexts, but this extends the sentiment of previous studies that various minor technical issues are reported, and reduces general confidence of use (Koutsabasis et al., 2012; Nisha, 2019). There were regular calibration issues, from still functional to more disruptive issues. Both with VR and AR, particular issues repeated around scaling of imported elements (coming into too small/large, incorrectly rotated), and interface/control precision, resulting in many cases of difficulty in place elements accurately (e.g. both touchscreens, and VR controller), with alignment, as varying degrees of imprecision, also not consistently supported or functioning 'snapping' to geometry.

Whilst the sentiment for most was still hopeful, this landscape of issues leads to a lack of total confidence in SC technology and perception that such issues detracted from or hindered important design focus/progress.

This was summarised by Birmingham City Council, as “not yet reliable or accessible enough for practices to make more significant investments”. Similarly, by Define’s decision to use Trueview as a full package with human tech support, as a means to remove integration and calibration away from impact on the design team focus: “everything was provided” (see 6.2).

Compromises for Accessibility: Power vs Mobility

To gain spatial capability, compromises currently need to be made. First, if running on mobile devices is required, there are limits to model complexity due to power and battery life limits (Gill and Lange, 2015). Second, to provide access to a wide range of users, there is a desire to provide a simple, easy-to-use interface that is not cluttered by large toolsets (e.g. see the 5.2 Arkio interface design approach). By comparison, the SC software explored was felt by several experienced users to be lacking some of the basic features of more established desktop software. Role based user modes could be implemented to allow users to switch between levels of interface, i.e. ‘beginner, advanced, expert’, with associated levels of ease-of-use vs depth of capability, with design choices aligned to appreciation of tolerance for cognitive load (Ishii *et al.*, 2002; Raja and Calvo, 2017; Umair *et al.*, 2022).

Quality of 3d models, textures, and their rendering were discussed as areas for general improvement, although they appeared to be at an acceptable level. Immersion in the 3d environment emphasised these qualities, for most it appeared that Google Earth VR, being photo based, initially provided a very believable level of detail. Following more extended periods and on reflection, there was some feeling that the resolution could be higher. For Arkio, which has a much greater interactive capability, the models are deliberately low, which presented some disappointment for students trying to import their higher-resolution models.

Simple modelling was a stated intention for Arkio in their software design (similar to the very established Sketchup). However, partly, the approach seems to be related to making the software multiplatform (desktop, mobile, VR, AR, etc.) and has to match the lowest computing capability requirement (i.e. mobile). Several participants felt that the environments were too limited for model detail at the human scale in VR. The level of what might be considered acceptably ‘illustrative’, or ‘indicative’ for urban design type of work varies by scale, that is, for smaller scale, more detail and vice versa. The software emphasises design action and interactivity (design, collaborative actions), over realism, or rendering qualities, such as advanced lighting (Nielsen, Delman and Lossings, 2005; Bishop, 2011). This is not intended as a critique of the software; these are largely the current limitations of hardware, to which software design is aligned.

This geometry can be changed in plugin settings but may reduce stability, especially in a larger-scale setting of an urban design project. There are many detailed technical considerations relating to these issues (understandable from the developers’ view), not within the focus or scope to cover here. Nevertheless, the current compromises that need to be made present a trade-off that the new users testing here were sometimes disappointed with, especially where they are used to working with much more powerful non-SC systems (e.g. from the case of using Rhino on a dedicated laptop). Though less of an issue than in the past, as there is functionality, there are greater limits to detail of geometry, rendering on the kind of mobile devices that support collaborative setup, such as multiusers in VR, or engagement using tablets for AR outdoors, which aligns with the fundamental (AR/MR) 'compromise' as defined by Wang et al. (2019).

Context, Data inputs

Participants indicated a need to better understand place within the SC design process, as relating to various layers of contextual consideration, for more informed design decision making (Han *et al.*, 2013; Van Leeuwen *et al.*, 2018). Significant gaps were observed when accessible spatial computing was used. SC has the potential to allow spatial communication of various types of data, for example, site analysis layers or construction instructions, in ways that integrate into the user's view. All participant types from designers, students, and the public discussed areas where greater contextual detail was desirable to provide real-time context for design review/decisions (Chen and Huang, 2013; Fares, Taha and EL Sayad, 2018). There was still a large gap between current capability experienced and a more ideal capability as requested by previous research (Chen and Huang, 2013; Shushan, Portugali and Blumenfeld-Lieberthal, 2016).

The range of current examples explored, presented technical limits, and further compromises aligned to the need for accessibility, such as mapping being free or low cost (Google Earth, or OpenStreetMap in Arkio). In addition, data layers were static, whereas users indicated a desire for interaction with the contextual data though design manipulation (change), and/or as allowing better integration with editable design layers (Chen and Huang, 2013; Krietemeyer, 2017). This would also support the ability to distinguish between design analytical data types, such as highlighting private and public spaces (Google Earth VR), as well as via better systems for viewing, managing, and simulating layers of contextual data to increase practicality (Alonso *et al.*, 2018).

While users found that immersion in photo-based VR (G.E) gave a good overview of the design space, it still had limited depth and detail for understanding the intricacies of the design context. While this is no different to the desktop version, which has firmly established use, there are very few alternatives or provide support to more detailed options available for use in SC.

There is a need to move between scales, and as presented, a pertinent issue relates to experiencing appropriate details at different scales. As reported by Koutsabasis *et al.* (2012), 3D models loaded into mobile systems still have much more limited geometry and materials. Having a large-scale model with many details is a challenge but is increasingly possible in nonspatial, non-accessible systems. Though some appreciated limits presented by its emergent nature, several users' judgement was made in a more direct comparison to wider computer modelling capabilities, therefore perceiving SC as less capable.

Full GiS tools have become available for VR more recently, such as CityEngine/ArcGIS (*360 VR*, 2024). However, these are much less accessible (more complex and expensive resources). The Arkio collaborative design software offers integrations of open source mapping/building height data (*3D maps*, 2021; *OpenStreetMap*, 2024), as a free and simple implementation (clicking a 'Map' button). While this allowed simple, basic building massing and low-resolution ground plane texture, by comparison, to professional mapping and GiS standards, and even more so for advanced game engine-based rendering, the image resolution is very low. Participants indicated its limited use, as mapping from strategic scale detail, viewed at human scale (1:1), represented a very pixellated building or map, offering only basic support to design understanding.

This highlights the gap between what the research suggests will be valuable and what is currently easily accessible. Both hardware limitations (mobile) and cost-accessibility implications that influence software design choices, seem to limit what is currently being done. Since the research events took place, newer software has become available that builds on this function. For example, using Google Earth data on mobile headsets and providing more functions. For example, 'EarthQuest' produced by a single developer (*EarthQuest*, 2024) and tested recently by the researcher, shows how the context of issues can change quickly, towards make this an increasingly accessible field. Amongst the practitioners, understanding local cultural conditions was a high priority task for urban design, to align the design process to community needs. This was felt to be a particularly important aspect of longer-term stewardship, often being subdued in more financially driven development. In the currently accessible SC, there was little built-in provision for culture or other layers, such as environmental analysis, unless the user developed specific inputs (not tested), aligning to Yu *et al.* (2022). These gaps are explored further in Section 7.3.

Precedent, Presets, Library

There was debate on the extent of pre-made of components and material, 'library', both for the AR and VR software. Some felt that having these elements gave less experienced users a means to immediately visualise design ideas. Others felt that in a public participatory setting, this could lead users towards certain types of design choices, elements, styles, etc. which opens debates around transparency, political bias, and persuasion (manipulation) (Arnstein, 1969), as well as the general contested nature of design (Black, 2018; Bellentani, Panico and Yoka, 2024b).

For the AR walk case, a pre-made conceptual library was key to the basic function, allowing speed of scene production, derived from various technical limits and need to work with new, inexperienced users, on site.

For Arkio, the library aligns to a general minimalist approach, with a focus on accessibility – too large a library could be overwhelming. Future systems could allow a spectrum of preselected or open creative means, depending on the context. Specific technical and contextual reasons impact who makes or pays for the library.. Arkio allows bespoke elements to be loaded by users with that capability, and a slightly more extended library can be purchased if desirable (monetised addition).

Capability gaps across Stages and Outputs

Exploration revealed that the range of commercial SC software with usable relevance to Co.UD (see 5.2) is currently very limited. As Brown *et al.* (2017) define, each offers different capabilities and has specific compromises. There is great scope to develop a range of software, and/or add capabilities to available systems, to enhance use for different stages, types of process, users, roles, and the many layers of urban design work.

In many ways, the software gaps appear at least as significant to gaining adoption of SC than hardware gaps. There is a lack of high-value applications (killer apps) that present a fundamental case for SC use over nonspatial systems. The range is even more limited for more accessible mobile devices, such as head-mounted devices, tablets, and mobile phones (limited vs. dedicated graphics, PC-based headsets). Some non-SC software has been ported to SC (for example, GE. VR – see 5.3-5.5), but there is still much opportunity to design Urban Design software that works natively as spatial interactive capabilities–Arkio, currently being the only UD aligned, option in this regard, which has its particular strengths and compromises.

The main current capability/application is for the user to enter into an uneditable model for design review in VR and/or similarly placing an uneditable 3D model into AR space. For mobile devices, undertaking urban design within SC and Collaborative Environment is only currently offered by Arkio (mobile capable) and Sketchup (desktop only–mobile, only a viewer). With such a limited range of tangible examples, many less experienced design/SC participants (e.g. students, public) perceived the capabilities and limitations of specific SC software to be limits of SC in general, rather than appreciating that the software landscape is still emergent and might hold much further potential.

Affordances

Objective 1b: Assess functional, environmental and emotional affordances offered by spatial computing

Aligning to Davis' affordances framework (2020), through the various collaborative settings and desired actions, users were either requested or demanded, encouraged or discouraged, refused or allowed, to perform certain collaborative interactions.

Space, Scale, Detail

Across the data set, participants repeatedly highlighted a key benefit of SC as being the first-hand, perceptive understanding of space, scale, and objects within. This aligns to the general, longstanding understanding as presented across research literature, of SC placing user in a 'Perceptually native' position (Seichter and Schnabel, 2005; Broschart, Zeile and Streich, 2013; Broschart and Zeile, 2015; Calixte and Leclercq, 2017; Chowdhury and Schnabel, 2021; Matthys *et al.*, 2023). Similar to the conclusions of Soria and Roth (no date), most participants had a strong emotional response to SC use. This includes both excitement and trepidation.

Many statements were provided as both general and specific areas of positive reactions. Almost all first-time users, used words and phrases that were delivered as strong emotional reaction, such as positive 'cool', 'wow', 'useful', 'interesting' (AR, VR, different tools), a few more neutral-negative: 'weird', 'trippy'. Most participants were not able to expand on the significance to provide an explanation of the benefits. Perhaps this was due to the difficulty in articulating a general visual, emotional experience, especially live or shortly after, within such a socially dynamic collaborative setting. In addition, users may not have known exactly how it might have had an impact in the longer term, or how exactly it had impacted. Despite this, the majority view was that seeing design ideas directly in perceptive 3D space was fundamentally and intuitively useful to design, especially in terms of intuitively understanding space and scale (Calixte and Leclercq, 2017; Saßmannshausen *et al.*, 2021).

As a specific example, in using Google Earth VR, several participants across the studies noted enhanced detail compared to the desktop version. They felt they could see more and were able to provide an overview of the space that was open to choice, beyond even what could be achieved in person (i.e. flying). This is interesting as the VR version is not of higher resolution; it uses the same satellite/photo data as the desktop (same photographic data). Hence, there was something about the immediacy of understanding design space as a direct visual experience that provided this perception. It was a cognitively more direct appreciation, which revealed something of previously hidden information (Olbrich *et al.*, 2013), not only a perception of higher flat resolution but also through a resolution seen with spatial depth. This also ties very closely with the summary of some researchers that contextual design environments may be better understood from the individuals' perspective (Nisha, 2019), and in ways that are visually intuitive (Khan, Loke and Khan, 2017; Russo, 2021). There is still some uncertainty about how exactly this is useful - for what purpose(s)? The results support the idea that a fully 3d perceptive experiential communication has holistic benefit for the design of 3d perceptive environments – as a more direct, less abstract form of communication.

The visceral experience also emphasised some negative judgements and reactions, such as highlighting the lack of features, overly simple material and geometry qualities, and/or frequent audio-visual glitches. While SC may benefit a fundamental holistic experience, it currently suffers from a range of specific issues that influence the accuracy and believability of that experience.

Following this evaluation, there is scope for research to look into more detail, particularly to understand the varying underlying mechanisms for what Griffith and Alpert (2022) outlined in broad terms, as 'downstream benefits'. Various studies have shown indication of performance improvements via metrics (Fonseca *et al.*, 2014, 2014; Umair *et al.*, 2022), though there is a need for further longitudinal studies that illuminate, broader range of urban design and 'benefits' and not least, deeper understanding of the underlying reasons for particular impact on design quality, including social and individual cognitive design process studies. These also need to be related to non-digital, real, physical, tangible design actions, such as drawing with a pencil and paper, real on-site construction, etc.

Sensory, Cognitive Experience

In a broad sense, the immersive nature of spatial computing has been shown to place a greater emotional emphasis on actions undertaken (Felnhofer *et al.*, 2015; Oleksy and Wnuk, 2016). In use, both positive and negative experiences were shown to be emotionally amplified, manifesting along a scale of effects, from producing engaging clarity through to increased confusion and frustration.

In many cases, this was a highly positive influence, as stated where space and form were understood more viscerally, akin to and connected to our everyday experience (Neru, 2021). It also negatively influenced audio-visual anomalies, where a variety of anomalies were practically and cognitively distracting to the design process (Raja and Calvo, 2017). Additionally, in the current immersive conditions, the undertaking of tasks that would otherwise be rather simple (in the physical domain) became cognitively taxing. At times, VR hardware had concurrent technical issues, which conflated to present highly chaotic, disorientating experiences. While the majority of participants maintained their use and interest, a small number of participants showed reluctance to use VR immersion after a few attempts. One participant even stated, It's not for me.

Realistic actions

While current SC, particularly mobile rendering, does not look exactly realistic, each iteration improves the capability. Increasing confidence in the visual shifts focus for SC developers who are transitioning to focus on getting the interactions right, so that actions align to visual experience, as an important part of a convincing emotive experience (Cipresso *et al.*, 2018). The results indicate continuing gaps in this regard. On several occasions and with different software, participants were lost in immersive VR. This was a particular issue in Google Earth, likely due to the extensive scale of the environment, that is, from human scale to local region, to the whole world. At the human scale, some users would find themselves in an unfamiliar place and like in real life, felt lost, without appreciation of where to navigate. The immersive nature emphasised this effect, with participants asking for a map, directions, and seeking landmarks from those outside the headset, as described by Bruns and Chamberlain (2019). This also occurred to a lesser degree in Arkio (a much smaller mapped environment). Through more extended sessions, this highlighted that the getting 'lost' was compounded by not being able to 'move' - being stuck due to a lack of personal understanding of the controller mechanics (e.g. which buttons) and the specific affordances provided by the system, such as pointing to the sky and pressing a button to exit from the human scale view. In two different recorded examples, users were positioned the ground plane for an extended period unable to move and did not want to ask – this 'lost' seemed to be beyond a 'physical, experiential lost' to somewhat 'cognitively lost', unable to navigate the complex task. Although the exact gap was not pinpointed, the interface did not provide equivalent affordances to real-life movement (which the user was capable of).

In the near future, highly realistic immersive elements and spaces may start to impact a user's perception of reality more significantly, with further unknown cognitive effects. Such a potentially disruptive impact has been discussed in a small number of previous studies relating to urban design, of a practical (Umair *et al.*, 2022) and cognitive nature (Raja and Calvo, 2017), but needs to be understood further. As the realism gap closes, there will be increasing importance on software stability and digital affordances that logically connect to real-world affordances.

Actions, shared - design space

Multiple users working within a shared design environment (both AR and VR) allowed users to freely position themselves, move around, manipulate objects, and communicate in 3d space. In this way, users can immediately see and interact with each other's design changes, affording instant feedback and a fluid exchange and process of design iteration. In general, this facilitated co-design, rather than separated processes, especially once the system was understood by several members of the design team (Chowdhury and Schnabel, 2021; Chowdhury and Hanegraaf, 2022).

This ability varies between formats and is limited by hardware and software affordances in relation to individual and collective participant capabilities. Participants were required to perform combinations of hand and arm movements, gestures, and buttons to press, for which they varied in appreciation and speed of learning. Given a relatively short time, these abilities improved for all, which then also increased the number of design actions. These factors impacted the quality of the group design outputs and, most importantly, their own perceptions of success.

Success and difficulties were found in immersive VR collaboration. The ability to work in the same virtual space with real-time sharing of processes was collaborative. However, owing to the operating system focus on avatars, which are specified by individual accounts (see – 5), users were not easily able to know who was who. In addition, due to avatar scaling proportional to the scale of the user's view (up to 1:1000), users found that they were constantly in the way of each other (blocking the view). Hence, while there have been attempts at following personal space rules as reported by Šašinka *et al.* (2019), including verbal communications on this, the interface and size of avatars meant that this was made very difficult. More is to be said about avatar social consideration (see 6.2).

In addition to the above, and most significantly for those learning design/the software interface, it became clear that owing to users not being able to see others' full actions, controls, or interface (process), only the resulting change. This is a major advantage for AR, where the collaborative aspect is still largely embedded in the real world, where people can see each other and their physical interactions. This could be explained further by looking at approaches to learning, such as 'learn by doing' (Gibbs, 1988), where watching others is an important first step in the learning process. For VR, a range of macro-and microscale interactions would need to be replicated.

Current SC design compromises lead to abstraction from realistic levels of nuances for users to see and greatly appreciate interactions. Some macro interactions could be seen, such as general movement (position) and angle of view, some broad expressions (head tilt, etc.), aligning with the required social protocols set out by Gül *et al.* (2013), and were also supported by a much more natural range of expression in audio (discussion). However, for design tasks, many of the physical tactile interactions are not shared with other users, either as overlooked or due to wider organisational design decisions (discussed in 6.2). However, in design, they are a key method for communicating, and particularly for learning. The watching of others in a real space (as AR affords) and seeing physical actions as communicated by default (unless hidden on purpose) seems crucial. Standard digital systems (e.g. laptops) often obscure this process to other users. Rather than redesign, for a shared spatial affordance, this lack of shared visuals is still present to become a key limitation of the VR environments tested due to choices in operating system and software design (all types tested).

Hence, the specific mechanics of interacting with objects and spaces are often hidden, reducing the ability of users to see or understand what others are doing, and more importantly, how they are doing it. This is extended further between those in VR and those outside, who can see very little. Even where a screen displayed the collaborative space and could be focused on one individual action, these types of details were lost.

This hiding of physical manipulation reduces the ability to learn from others. This was a particular problem for educators, whose main task is to relay information to others. For example, if two are in a VR collaborative environment, one cannot current show the other, where the button is by pointing to it, or even pressing it themselves, showing someone 'how to…'. However, this would be a basic primary affordance of real interaction, even when using a simple pen and paper. Watching someone else sketch can convey so much about the angle, pressure, movement, and of how one holds a pencil, as well as the wider emotional, physical mindset, all of which might be learnt from. Most of these types of micro-affordances are hidden in the current collaborative environments used.

While a lot of emphasis is placed on non-verbal expression, perhaps due to VRs' current development focus from social media perspectives, for designers, the basic mechanical functions are not expressed at all, and for are arguably a lot more important (Vosinakis *et al.*, 2008), especially at the initial stages (Nisha, 2019). Being able to share views or take on a role to allow spatial-physical communication of these physical interactions is a key part of collaborative design action. Such forms of real-world communication follow a complex array of understandings.

Considering these insights adds to our contextual insight, moving beyond broader statements of increased motivation and engagement provided by verbal cues, body movements, gestures, etc. (Koutsabasis *et al.*, 2012; Hong *et al.*, 2019), there is a need to continue to understand which key interactive mechanics are most essential for porting over to immersive interfaces, with relation to feasibility (every micro transaction may be too resource-heavy).

Overall, there was a regular perception, at least in principle, that AR was more aligned with design collaboration. It provides clear interaction-communication within the shared space, facilitating multiuser design actions in context. In the apps tested, AR and VR are still quite separated. For collaborative working, it became clear that setup and navigation in real and digital spaces were quite different for each. AR, which is situated in real space, allows freedom of movement with an overlay of elements. Passthrough mode, which offers a mixed reality experience for VR headsets via a camera, allowed users to see the design view, but the benefit was very limited beyond this as the software did not take advantage and due to users still being situated within their own physical boundary. More useful for co-design would be a shared physical space with shared digital objects placed in the virtual space for all users.

In summary, the communication of physical mechanical interactions is a vitally important aspect in the process of a shared construction-based environment, which seems to be underappreciated in the current design of SC systems. For design work, however, this seems even more important to practical design interaction than the current (social media) focus on body language (avatar).

Interactive, Ergonomic - Tactile (User Interface: UX)

In live events, users were generally observed as developing an understanding and ability to interact with spatial objects of SC. The key interactions included the following:

- Transition between scales, by grasping the space (via controller buttons) and stretching hands in-or outward
- Picking up and placement of objects in 3D space, then ability to 'walk' around (real physical movement), or move via pushing towards desired location as teleport, or 'skiing' movement (pull both controllers, pull yourself forward) - related to natural movements
- Move between virtual spaces, as portal ('bubble', pick up portal sphere)
- Aligned to real-world interactions with established real interfaces, artists 'palette, that is Arkio palette
- Nested features, press button to reveal more related uses, contextualised features / or by interactions

Reflection on first-hand testing, discussion, and observing others highlighted two main types of interactions. Some require 3d physical-spatial actions (e.g. spatially rotate, as a door knob) and some are traditional digital (navigate menu, by selecting (click button) from a drop-down list). Current SC software tends to use a combination of both to varying degrees.

These differences are not immediately understood nor explained by software guidance; perhaps expected to be intuitive. However, from the actions undertaken within the events, as part of the learning and design process, this was not obvious to participants. Key examples related to rotation in Arkio. Several users, including the researcher (first-hand), found the ability to rotate to be more difficult than expected (as discussed with Arkio, see 5.1). Many users asked, 'How do I rotate?'. The realisation, to reach in, pick it up and rotate the hand as a more natural affordance was not expected. This may be due to embedded knowledge from prior experience and training of more abstract mechanics, that is, expecting a rotate button: moving mouse to menu, pressing button to select tool, click tool on item, also as suggested by Johan from Arkio (5.1).

One participant felt that using Sketchup VR was akin to physical modelling of 3D objects, as the user moves and picks up things and pulls them as part of whole-body movement (though it could apply to AR too), which was more like real-world construction. Discussing VR, they suggest that access to understanding the design is improved by being closer to real-world physical interaction. They gave an example of designing their interface system as inspired by the paint palette and tool kit that you have on your arm.

Arkio suggested that the requirement for accessible interactions is similar to that of physical function and that there is a need for unlearning, due to many being embedded in established processes. However, reflecting on this further (first-hand testing, including collaboratively with other participants), it seems that users may not be expecting a need to reach in and grab like real life-, because of the sequence of preceding interactions, which were not like real life – see Ecological Validity assessment – i.e. a mismatch in level of behavioural realism. Whereas the real life 'natural affordance to pick up and rotate an object requires touch. In picking up an object in VR (Arkio, similar in others), no feedback or affordance is granted until you move close enough to physically touch the object, judge it with the fingertips, and then where you have only two choices: move it or leave it. This does not directly align to digital options as presented, where we can pick up from very far away, but cannot ever feel it (currently), and we can then move it, copy it (pressing another button first), extrude the shape, etc. All of these actions are afforded from any distance; you can pick an item from any distance. Rotating is only possible once close.

In digital 3D space, such as SC (and in Arkio), you can already pick up the item from far away, so a physical impossibility is made possible. Hence, if the first interaction with the object is beyond real-world capability, then many users' logic would not follow that they then need to re-apply real-world logic to a need to rotate. Similarly, copying is afforded in Arkio by picking up an object and then pressing a button combination that cannot be seen before picking up the item. This process, as a physical motion-based logic, started to make more sense as experience was gained with the immersive environment and/or objects.

This example highlights that the affordances of SC are often not exactly like in real life. First, there is (currently) still a controller or digital interaction (interface), and there are possibilities beyond real physicality (that are beneficial, beyond real physics). Thus, actions are perhaps not as holistically intuitive as has often been claimed (for example: (St-Aubin *et al.*, 2010; Fonseca Escudero *et al.*, 2017; Van Leeuwen *et al.*, 2018)).

Generally, less experienced participants were more reserved and/or limited in their physical (real) bodily actions and movements. It was not entirely clear why this might be, and would be interesting to test further. This might include whether movement is something that changes with SC experience and/or by background experience with real-world construction. It might also be impacted by the current affordances and specific limitations, such as the way boundaries are setup, integration, and the ability to be aware of physical surroundings.

Actions based on hand tracking may reduce the gap further but did not work smoothly enough at the time of undertaking primary research. Since then, hand tracking has advanced further, particularly with Vision Pro

(Apple.inc, 2023), which relies entirely on a combination of eye and hand tracking, as well as SC digital pencils such as MX Ink (Logitech, 2024), or more mainstream integration of haptic feedback systems (gloves). With greater adoption, these types of technologies may begin to allow more natural gesture-based interactions.

Precision

For design work, precision was found to be a significant limitation of current technologies, as in Ioannidi, Gavalas, and Kasapakis (2017). This is particularly true for AR using mobile devices, which are more severely limited by the 2D screen as an interface for 3D work. Therefore, the ability to judge and change object scales using MAR presents several issues. First, the screen size was a basic but fundamental limitation, where details could not be seen or interacted with as a limited field of view (even using larger tablets). This aligned to using fingers, as a more basic interactive interface, made interactions imprecise. In VR, working in the space, with hands free and controllers, there was generally much greater control than AR, though presented some imprecision, coming from software implementation. The 3d modelling tools used, when compared to desktop/laptop, had a lower ability to precisely orientate dimensions via numerical input or highly precise snapping. The 'tracking' issues, as discussed for over a decade still persist (Chi, Kang and Wang, 2013; Alrashed *et al.*, 2015; Ioannidi, Gavalas and Kasapakis, 2017). This supports the development of interaction via natural hand/body movements (Raskar, Welch and Fuchs, 1998).

6.2 Q2. Influences on Decision-making, Collaborative Participation

The following section considers the relationship between spatial computing technologies and the capacity of individuals and groups to create action within social systems and interfaces that may influence them. The initial sections compile key implications, followed by further reflection on existing knowledge.

Co-Design Process

Objective 2a. Assess impacts on effectiveness of design process and activities, in terms of scope, depth and focus

Communication, Coordination, Roles

Good collaboration relies heavily on the level and qualities of coordination (Çöltekin *et al.*, 2020). The virtual or augmented shared design environment (i.e. Arkio or AR walk) was observed and felt by participants to provide an open possibility for collaborative working (Alrashed *et al.*, 2015), compared to individual device processes. Whilst it did not perform flawlessly, due to limits in current provision, for many it encouraged a shift towards a collaborative process (whether conscious of this or not). In the shared environment, different users were independently and concurrently able to change their actions, from adding design elements, to analysis, to becoming a 'tour guide', to change their perceptive scale, orientation and so on (Koutsabasis *et al.*, 2012). These actions are both free choices for the user but can also be influenced by intended actions and social roles.

Implications

- The open environment allows equal opportunity to partake in design decision-actions (once users can use the system)
- Many types and nuance of verbal and non-verbal communicative cues, are currently hidden in SC compared to real interactions
- Immersion/virtual environments can suppress communication, creating greater social disconnection owing to altered interactions.
- The playful nature of the virtual environment can support engagement and cohesion, but can also distract from productivity
- Familiarity is important in difficult social conditions; until wider adoption, traditional methods will still provide an advantage.

- In any collaborative process, there are interpersonal relationship considerations that could unite or disrupt cohesion and ultimately influence the quality of design outputs.
- Questions are raised around design scrutiny, when fun and immersion are prioritised

While knowledge of what to do and how to do it was not immediate, it did develop over time. This process was aided by collaborative working experience, of which only a small handful of (mature, practice-experienced) students had prior experience. For most of the researched cases, the design teams (participant groups) were new to each other, with less established social roles and bonds, impacting the initial cohesive processes (Salter *et al.*, 2009). In the VR co-design environment, users were constantly overlaying and deleting each other's work, and largely going about the process in separated ways, as a broadly un-coordinated process. This effect was reduced over time as users became more familiar with the system; they started to talk to interact more, but expanded the claim that collaborative environments need "no prior training" (Fonseca Escudero *et al.*, 2017). From both technical and social standpoints, it is likely that some training is preferable.

By experientially placing the user in a shared digital space, they were also isolated from each other in real space. In addition, due to not seeing each other's interface actions as previously discussed (see 6.1 b), certain aspects of basic shared understanding were blocked: for example, clearly seeing what another team member is doing or trying to do. Whilst collaborative issues were partly due to wider group coordination issues, the open spatial environment had no tools or management interface to facilitate the complex collaborative process, beyond the provision of an open area to create/move/interact/talk, though in some instances with a slightly reduced capacity compared to real life.

Level of collaborative actions and discussions

Irrespective of the technology, participants varied greatly in the level and types of discussion. Some had focused on design discussion, some were very playful, some were unfocused, some were highly engaged, or took the task seriously. These social dynamics, interpersonal relationships, individual personalities, and approaches (Imottesjo and Kain, 2022; Nguyen and Mougenot, 2022) influence interactions using SC technologies. Still, the process between AR and VR cases seemed to differ in the level of vocalisation. In VR virtual environments (VE), most acted, at least initially, as separate entities within the space. As they became familiarised, most increased in verbal and physical design interaction with those inside the virtual environment, but far less so for those outside of the VE. Although they could have joined laptops (they had them), most did not, and therefore, were not able to see or interact with those processes. This indicates that such physical isolation likely impacted the atmosphere of the real space and social interactions, either due to confidence or engagement (Rizzo and Galanakis, 2017).

FIGURE 69 – EXAMPLE: VR AND OTHER USERS ISOLATED FROM EACH OTHER IN THE REAL SPACE

Though a different space and activity context and much simpler design action, AR vocalisation was by comparison more immediate, in a quicker, greater extent. This also seemed to result in a stronger process of iteration through trial and error in terms of learning the interface. Caution is needed in comparison, as the VR software was generally more advanced and had a higher learning curve. While participants were initially very quiet in an initial phase learning the physical interface and specific software interactions, this varied by individual and across the groups, and in the following weeks of more extended use, there were broad increases in vocal and collaborative design interactions aligning to findings by Wang and Dunston (2013) (also aligning to resolution of initial audio issues).

The effects of and mitigation of isolating experiences were not found to be discussed extensively in the related research reviewed, except for a brief mention by Delgado (2020, p. 5) as a limitation of VR. However, this presents a key challenge (an opportunity) for collaborative SC design. Encouraging greater social coordination might be best revolved via a blend of VR and MR capabilities. The research showed that the ability of users to see each other and see what they are doing physically and digitally is vital – that is, blending the virtual model/space with the real, to promote the sharing of collaborative interactions (see 6.1 a-b) as a collective integration of knowledge (Dupont *et al.*, 2012).

Virtual Identity (Avatars)

The primary use of avatars did not generally facilitate non-verbal communication and presented several issues for collaboration in the virtual environment.

- Avatars were tied to specific devices/accounts, which does not align with the requirement for open, flexible use, such as the need to regularly switch between users, without large gaps in setup. This often meant that users had random, unaffiliated avatars, which caused confusion and misrepresented identities. Quick switching of users, with name input only, would prioritise critical information. Avatars could be improved, but a more mixed/augmented space to design would remove the need for avatars. A more useful key information requirement would simply be to display a username, perhaps - role, activity (as a tag or symbolically).

- Facial expressions or full natural body language (only basic avatar motion) are represented. Potentially useful but not a priority for design collaboration.
- Verbal Communication (audio) can support more nuanced collaborative understanding, though issues and lack of non-verbal communication (social issues, as in the previous section see above - 'Verbal Communication'), may be related.
- Actions, as process not shared visually – this is a key requirement for design collaboration

Previous studies, such as by Hong *et al.* (2019), indicate an overall benefit to avatar based working vs. without. This point is not fully disputed here; rather, to highlight that there is more nuance and clearly a gap between real rich interactions in real life and still somewhat limited representation of users as a 3d avatar, that ideally can be further closed (Weber, 2016).

Engagement

There is a relationship between engagement and acceptance of SC interfaces/actions. As stated in (see 6.1), the multi-user immersive environment natively communicated a shared process (though not without gaps). For the collaborative process, this meant that users had independent control over their own spatial position and interactions in the 3d environment (Sørensen, 2006; Broschart, Zeile and Streich, 2013; Broschart and Zeile, 2015; Calixte and Leclercq, 2017) and as such were less controlled in the narrative presentation. Users did not rely entirely on someone else's tour (of a presentation, on a laptop, etc.). The ability to move freely allows different objectives for review to be explored without needing to state purpose or review intent, promoting more participatory input and better accounting for individual preferences and objectives (Alrashed *et al.*, 2015). Aspects were assessed for importance before asking further questions rather than relying on the presenter's control.

For example, this revealed an interesting observation of students' design process:

> *'I found that the students had placed a model of a person sitting on a toilet with a plant pot on their head' [researcher reflection]*

Reflecting on this further, as a tutor, this access to understanding (a student's) design is not often seen when working on individual devices. Typically, we only obtain snapshots of the process, where specific outputs are presented as curated results (e.g. a selected sketch of a scene or a final rendered image). In this case, the tutor (or design reviewer, stakeholder in practice) is engaged in the same way, with the same freedoms to see and do as other users in the 3D space, which revealed parts of the design process that might otherwise be hidden, as a better shared understanding (Alrashed *et al.*, 2015). Expanding on the discussion by Broschart and Zeile (2015), this indicates that unstructured elements, often considered unimportant, 'inappropriate', or frivolous aspects of the design process, could be useful for learning, as well as engaging others. As an example, when users were lost, those who communicated with others and sought help were able to resolve issues effectively. This open ability, liberated ability to share content in fundamental ways, facilitating a freedom to appreciate the design and fluidly move between social modes quickly, emphasised participant strengths and weakness (though it could be emphasised further), more akin to real 3d space, and some online collaborative software (for example Miro, (2024)).

Design process and approach

There was a gap between the potential of the SC to support the design process and its actual impact. In various ways the learning curve of using AR/VR tech found less 'absolutely intuitive' than is often indicated e.g. (Khan, Loke and Khan, 2017) and did impact workflow in ways that were not always positive. This caused some users to become highly frustrated, particularly in more widely problematic collaborative scenarios (lack of cohesion, time pressure, etc.).

- Technical issues and limits can reduce output quality, leading to designers' preference for non-SC solutions
- Immediate design feedback of SC can speed up iteration
- Interactive design process being hidden in SC reduces effective design collaboration and refinement
- More could be done for SC to document and relay the design process
- Questions are raised around design scrutiny, when fun and immersion are prioritised

Engagement, Participation

In live events and their reflections, participants stated that exploring various examples of spatial computing provided an engaging experience. Several even used the word fun. This ties particularly to the sentiment that SC interactions are usefully playful (Broschart and Zeile, 2015). Participant reflections suggested that feelings of enjoyment (being happy, satisfied with the process or results) had a lot to do with how socially active, collaborative the group performed. This adds examples to the discussion, of 'variable expectations' when SC applied in the real-world (Rizzo and Galanakis, 2017).

Beyond this, there were several indications that the preconception was a mixture of excitement to try it and being cynical of how good it really would be–a promise that did not match the actual experience. This was quite variable by participant, impacted by the types and stage of work, and most importantly, the wider social context/group dynamic. More specifically, the relationship between, what Gül *et al.*, (2013) outlined as individual and group characteristics, with relation to the level of satisfaction with their state of 'progress'.

This varied by participant level of initial interest related to ability and their individual/collective willingness to accept a range of (relatively) minor issues. This leads to variable reactions, from a kind of proactive problem-solving approach through to broad doubt and following lack of confidence in the systems, aligned to degrees of (variable) frustration. Again, varying reactions were related to the overall group dynamic, stated both as a reaction to and a catalyst of perceived problems.

- Facilitation using collaborative SC requires technical and social support strategies, to enable parity of input and perspective
- A shared environment allows co-design, but roles and objectives are critical to coordination, and SC can do more to support its facilitation (Salter *et al.*, 2009).
- Using SC teams with role clarity and agreed objectives had a more cohesive process, whereas those without a more disjointed process. SC needs careful integration into established design workflows to reduce disruption

A negative public reaction to students 'gateway design in Southside (see 7.5) demonstrated that AR had allowed some designers (participants) to realise that principal design ideas need to be tested prior to their design resolution. It illuminated a more participatory understanding and how one designer's idea may be naive to certain aims (social-political views). It was not certain the extent to which it being spatial had an effect, as simply holding a photo of the design may have had a similar comment. However, placing the proposal directly in context may have promoted a particularly visceral effect and emotional reaction. Further work could be conducted to ascertain this with more certainty via repeated direct comparisons.

Individual and Collaborative Capacities

Objective 2b. Explore the implementation of SC with relation to individual and collaborative capacities within the context of social and organisational structures

(Pre-) Conception, Acceptance

It was noted that many of the student and public participants, that is, those less experienced in SC/UD, were often quick to state judgement on the whole concept and spectrum of SC (technologies) based only on very limited exposure: review or testing. For example, viewing one or a small number of examples and summing up fundamental issues with SC are limitations of the specific hardware/software being used.

Confidence and comfort (ergonomic, stylistic and social perceptions)

Several participants came with and maintained the perception (preconception) that AR was not sufficiently developed to be fully reliable. However, this was also strongly aligned with a reluctance to actually explore or test an AR approach to justify this view. Interestingly, in the student explorations, they took the principal aim of an AR idea and developed their own interpretation, indicating that they saw the potential but were not confident in either the current state of the technology, and/or their own ability/experience with it. The latter feeling of it being a confidence issue was also given by the module tutor in a follow-up reflection. Even when fully given access to a demonstrated method (AR walk content with mobile apps 'Augment' or Thyng), only one or two from each group took the opportunity to try it, and even less with members of the public.

A major first impression issue for wider adoption highlighted the importance of comfort for users, in terms of both physical fitting and being socially acceptable/desirable (AlWaer and Cooper, 2020). As a physical interface, multiple users reported issues of comfort with headsets, relating to fitting the head and blurring or strain on the eyes. This appreciation formed part of the introduction to the use of VR by the immersive technology expert, who was very experienced in setting up a broad range of SC activities over several years, feels the need to pre-empt use by stating some of the key limits, as expected to be re-occurring issues, as an industry acceptance that issues of comfort will likely present themselves for some users. For example, giving best practice guidance for users experiencing mild cognitive effects from changing between immersive and real environments, that is, often with disassociation effects. Adding to the debate around the need for facilitators that are designer vs. event experts (AlWaer and Cooper, 2020), this supports the need for technical experts in more complex event scenarios.

Wider social perception was in multiple ways shown to have a great influence on acceptance of SC by individuals and specific group dynamics. This was also seen at levels of social-organizational experience, from very experienced designers and academic tutors to various levels of students and members of the public. For VR, comments and observations showed an impact on behaviours for many users, from mild embarrassment, for example, what they look like, the unusual movements needed, to reluctance to engage with the device. For example, as stated, if wearing headwear or makeup, or more broadly, social shyness, uncertainty. For AR, using an established 'tablet' format created an opposite perception. Devices were thought by some to be likely perceived as marketing and public surveys, giving 'the wrong impression' to potential participants vs. the actual participatory intentions.

Key influences on user conception of collaborative UD activity (Positive/Negative):

Pre-existing

+ As a new methods / technology, engaging (danger of being a gimmick)
+ Wider perceptions in the media, e.g. people getting hurt in VR
- General complexity of learning new hardware/software
- SC perceived as high-tech, 'will be complicated' (including social media/media influence)

Adds to above:

- Concern over inexperience with UD as a strategic, large scale
- Concern over inexperience with collaboration

Initial-mid

+ Cognitive excitement, experiential immersion, initial wow factor
+ Alternative viewpoint, new perspective on design, being in a previously imagined design space
- Difficulty learning spatial interface / interactions, controls, etc. under pressure of immersive action
- Frustration due to technical errors, issues
    - Physical discomfort: VR head mounted interface, blurring & eye strain – motion sickness
- Cognitive discomfort, including dissociation

Adds to above:

- Collective inexperience, dysfunctional collaborative / design process, unbalanced effort/engagement between users

Mid-long term

+ It continues to be a fun, engaging, interactive, and physical experience. Requires active, requires physical activity movements
- Physical tiredness

Adds to above:

- Dis-engagement with project, adding to further dysfunctional collaborative / design process
- External time pressures (other commitments, personal or professional)

- Poor, or non-communication, related to peer-expectation

Social-organisational access

Reflecting on the surrounding context of the research projects, there was influence from different perspectives and organisational types and levels. Limits related to nested factors, such as resourcing (Huxham and Vangen, 2000) and financial constraints, technology releases, personal or institutional knowledge and skill set, internal politics, as well as the particulars of room, equipment, and setup arrangements, right down to the specific interface and interactions within the technology (Saßmannshausen *et al.*, 2021). Various levels of organisational structure, agents, and their actions can present hard limits to what can or cannot be done. Little research has been found on the specifics of understanding institutional influences on SC, except for calls for investment in SC resources, such as by Reaver (2023) and very broadly for “investigating the governance systems, populations, or economic and political circumstances” (Ataman and Tuncer, 2022). Adoption has been discussed as an aim and metric of success (Wang *et al.*, 2013; Khan, Loke and Khan, 2017; Delgado, Oyedele, Demian, *et al.*, 2020; Misius, 2021).

As discussed earlier, technical conditions mean that compromises need to be made between computer power (e.g. energy use) and mobility (e.g. battery longevity/weight), which influences the availability of resources. This was also the case for the choice of software and setup for this research. The use of mobile headsets opens up much greater collaborative possibilities, as tested in (6.8) Colab RSS Arkio session, alongside a combination of organisational factors, broadly: 1. Facilities and equipment 2. Licenced software availability 3. Technical and Event Management Support. In combination, these factors changed what was possible and how it could be done - hosting multiple users. Prior to this time (a year earlier 6.6 Colab CRB), none of the conditions 1,2,3 above were fully met. The increase in resources has facilitated a more ambitious and complex setup. The project itself might also be thought of as an exploratory use case for the justification of such investments (Delgado, Oyedele, Demian, *et al.*, 2020).

Specifically, multi-institutional and various levels of access facilitated a shift in capability.

- 1 & 3. The host university (BCU) invested in a new institution: new spaces and fast networking, a dedicated department, multiple VR headsets, and a specialist on-site advisor. This organisational buy-in, related to longer-term, strategic decisions from key people who argued for investment in emerging technologies, with relation to ‘enterprise’ as a market for universities.
- 2. Software – Arkio, moved from beta experimental software to full commercial release, ensured stable performance, increased collaborative capabilities: downloading onto the devices: from the main meta store, rather than more complex instal. The provision of an educator licence opened access to multiuser setup features.

Intertwined with issues of access are issues of collective confidence in a system or specific technological application. For those less familiar with a particular social situation, perhaps, for example, a member of the public engaging in design activity, or students undertaking transdisciplinary collaboration, the ability to navigate issues of access was low (Gordon and Manosevitch, 2011), as they were still working to better appreciate the fundamentals, that is, of the design process, or contextual understanding, where new tech was a distraction (Ishii *et al.*, 2002). That the most accessible SC types see the highest adoption (Delgado *et al.*, 2020) indicates that wider systemic changes to hardware/software and organisational arrangements can rapidly change accessibility, and feasibility will have a strong impact.

In terms of organisational influence, SC manufacturers can also be significant.

> *"to see it in the early 90's. Even just the name, Virtual Reality, just had this presence about it…like, what the heck is that?" Interview (Lecturer in Visual Communication)*

From 'wow' to 'how', again.

Whereas, in the early days, SC types had an aura of the unknown, of being somewhere between science fiction and its actual very basic implementation. We can now see SC as encompassing a range of real-world options and products, each with competing design choices, operating systems, and UX designs. These choices align with manufacturer objectives, for example, for Meta, from a basis in social media. Though participants generally did not discuss it at the institutional level, there were several references to VR devices as being of a 'gaming' mindset, both in hardware and software design. In addition, it was notable that those with gaming interest-experience or lack the effected ability to use the controllers, for which the buttons and associated range of interactive affordances are very similar to console controllers. Whilst this has been promoted, to increase engagement and adoption (Imottesjo and Kain, 2022), it might also be seen as continuation of a barrier for some, due to physical interface, but may not buy into, and/or have different mindset, values, and aims to those of gamers (Murphy and Reeves, 2019). Currently, the options for financially accessible SC technologies are being driven with alignment to areas with the most mass-market appeal (Milovanovic and Moreau, 2017), which is gaming and media.

Wider Resourcing

Supporting the assertions of Delgado (2020), investment was raised by several participants as a key component of access to spatial computing. To some extent, this was felt to be a matter of scale and requirements. If there is a clear use case for the practice and the cost is correct (Define TrueView). At a smaller design team, where a direct use case is apparent and is no longer expensive, the cost for is not much for practice, relative to the very high costs of typical design software. For larger organisations, and for processes where Urban Design is involved, the costs might become increasingly uncertain, due to wider investment in training, not simply equipment costs, which is further muddied by the uncertainty of which specific technology, system, or workflow to invest in. For example, BCC, discussing a city model software that was so expensive, could pay for multiple employees. Some of the more advanced capabilities and potential are already available, but very expensive.

> *"the technology is still quite immature at the moment... there are solutions out there that can be really impressive, but they're not quite easy enough, or cheap enough or accessible enough to be truly practical without putting a lot of money and time in" (Planning Officer BCC)*

There needs to be institutional support and buy-in, but the question remains, with emergent technologies such as SC, there is no guaranteed return on investment.

Knowledge, Skills, Learning

It followed from open discussions that there were different levels of personal interest and/or appreciation for computing and/or gaming in general. For some, there was a more fundamental frustration in getting the hang of the basic interactions, such as navigating interactions, simple creation, placement, movement, and manipulation of objects. In VR in particular, movement around the space was an initial hurdle for many, which created a general uncertainty of action (Moural and Øritsland, 2019). This also connects to comments by several participants that the SC systems feel very game orientated: not only a physical sense, but of being of a technological mindset, style, and with associated skill set, including basic muscle memory for using the controllers. While SC is not inherently game based, the systems used, due to them being accessible as a resource (wider institutional investment), have a structure and particular mechanisms that people not into gaming are less familiar with as a whole mindset and tactile ability. This might naturally mean that some people were more or less likely to be engaged. This also raises further questions to be explored regarding how long does SC remain engaging? Is SC intrinsically more engaging? (as hype suggests), and in what circumstances does this vary? and the novelty factor wears off.

High-tech, Complicated (and... Glitchy)

For the participants, one of the key benefits of involvement in the cases was exposure to something they had never tried before. Aligned to this many and made comments which suggested they had pre-conceptions that SC was high-tech and/or complicated.

> *"Wait on Elon" (MA Student)*

For those that gained much experience over several weeks (7.5) of hands-on exposure to more accessible SC, this perception was much less repeated, although for those that had less experience, it remained much more (7.3). This suggests that there is a preconception barrier at work, likely due to a wider social (media) understanding. However, both sentiment and intent varied between users. There was some overlap between statements of 'high-tech, is complex' and 'it is not ready', which made it difficult to appreciate the basis of thought. This perception could be based on the individual's reluctance, due to their own inexperience and lack of confidence, or an issue with the technology itself. Some used the same statements positively: high-tech means, futuristic, exciting! These perceptions were not found to have been extensively discussed in the literature, with the exception of a survey by Goudarznia, Pietsch, and Krug (2017), which hints at similar uncertainty amongst people.

The impact of perception influencing (group) decisions was shown to be most clear in the case of all groups in Colab RSS (6.8), by choosing alternatives to AR for public engagement. There were statements of 'not ready', and later 'we are not good with it', and at the end, that several stated in person, or via written reflections that actually, it was easy. This indicates that there is a perceptive hurdle for those promoting SC to overcome. This was summarised by Johan at Arkio – expecting that as a generalisation, people can be fearful of new things and that full social acceptance of SC technologies would take a long time (was complex). Additionally, when considering the range of technical issues as demonstrated in this study, this quick perception is clearly not baseless and indicates that the legacy of issues previously highlighted (Alrashed *et al.*, 2015; Ioannidi, Gavalas and Kasapakis, 2017) are not fully resolved.

Several of the participants from practice, having tried and extensively tested various types of SC, indicated that it had strong value and support, but similarly they also lacked absolute confidence in terms of SC's reliability. This sentiment was clear in live testing, as discussed previously, with a range of technical issues being regular and persistent throughout. Generally, everything took longer than expected, unexpected errors occurred, there was a general uncertainty of protracted issues, and problems varied using different devices, applications, and methods. Less stable than many would have hoped by now, but perhaps not surprising, considering the expanded expectations aligned with technical advancements (Fonseca *et al.*, 2014).

For many participants, this was their first impression, and in reflection, this clearly formed a general view of SC being unreliable: 'clunky, Janky, not ready yet'. At the extreme end of this, some users experienced a total collapse in their virtual reality and were immersed in confusing chaos, such as combining multiple visual issues of hardware failure, which could have led to a more significant reduction in confidence.

Most participants in the live events had a general forgiving towards the emergent nature of the technology, expecting that the approaches used would result in potential issues. This was influenced by facilitators introducing this likelihood and hoping to offer guidance by providing a greater chance of practical, or at least tolerance, mitigation. However, evaluating across the data, there is a strong sense that SC was judged in direct comparison to the standards of current mainstream technology, which is generally incredibly refined and stable. For many, this was presented as generally having very little tolerance for the issues which were presented. This was not presented with anger or disappointment but with more indifference. The lowest tolerance could be found with hands-on testing in live events. This was particularly the case when participants felt under pressure more generally due to the number of tasks to complete, competing pressures, difficulties of group working, and so on. The benefit of doubt to slight technical problems was not always granted. For many participants, first impressions were often fundamental and quick judgements became lasting ones.

For students particularly, the culture of working in areas of urban design: architecture, planning, etc. are still emergent, to a variable degree, less confident to push beyond those aspects which are very established. The investment of time into something that is less accessible (in various ways) seems to be a lower priority when energy is needed to understand and navigate more fundamental aspects.

> *"They didn't understand the process and it was getting complicated, so they returned to traditional methods" (Urban Designer, on students' approach)*

Conversely, those finding most consistent success with AR and VR were practitioners who were extremely confident in the intentions and purpose of SC for their use case, and who understood the specific benefits over prior methods, likely allowing for their easier acceptance of any limitations.

The overall discussion presents a general problem for SC of infinite regress, as hard to pinpoint which comes first: cause or effect.

1. *building confidence to invest, when something is not absolutely ready,*
2. *investing when cultural confidence is lacking.*

An investment in knowledge and experience

The results point to a general knowledge gap that needs to be overcome for mainstream use, both in a general sense of SC technologies and specifically for various current and potential applications in UD. Urban design experts working with students understood that they were working with a lack of exposure, existing skills, and knowledge of SC. For many, there are fundamental life skills to draw on, such as the basis of hand-drawing. There is much scope for the integration of many more fundamental physical skill sets into digital (SC) capabilities. However, this was often not the case with some of the current SC interfaces, where skilful use of hand controllers and types of menu interfaces relied heavily on gaming experience, not design skills. As such, a key difficulty is that many lack extensive experience either in range of types or time with SC (Delgado, Oyedele, Demian, *et al.*, 2020). As one participant summarised:

> *"If I was more comfortable (familiar) with the interface and it had that toolset ('of an iPad' -i.e. more interactive) it could be useful."*

There is a significant challenge, especially for collaborative work, for all to enter the SC 'space' equally, not only in skill set, but in level of interest. In the context where the range of scope and potential is so broad, it was difficult to know what to focus on.

Specialists, towards general accessibility

In all cases, across the participant groups (practice and live), there were one or two individuals who stood out as having a particular depth of understanding SC, aligned to computing more generally. This was not only technical experience and competency but also an understanding of broader conceptual and social discussions on the types, potentials, and challenges related to the current status in practice use cases. Whilst we have moved on a long way from early prototype SC which needed highly specialised sills to get the technology to even work (Lange, 2001), the specialist requirement is broader. In practice, these specialists tended to have an official role based on their ability to action/discuss SC in depth, often with official title or informal social role. It was also the case in all the practice interviews, and in one of the live cases, that others would defer to this person on specific technical or conceptual matters arose in areas that went beyond the output and role of SC in the design process.

The specialist role was particularly defined at the very large organisation Birmingham City Council [see – 5.1], likely due to the variety and layers of potential application requiring expertise (Gil, Duarte and Syntax, 2008), where the specialist had been organisationally reinforced as such, through specific external training (further post-graduate study). In these cases, specific members of a practice tended to drive the application of SC in their practice. One slight exception was at Define, where several members were competent and aware (perhaps notably, all younger staff), although still two people stood out as very knowledgeable and had particular semi-formal roles.

The knowledge for technical and social setup was more specialist and less widely understood than initially assumed. The current requirement for specialists could mean that application into areas with low resources is unlikely to be implemented widely. For example, community engagement activities, which involved those who likely had lower design and/or design-specific technical knowledge, integration into the design process using AR walk (and the other student methods) was particular and presented an additional requirement for specialist guidance (Salter *et al.*, 2009) related to SC. However, it might be argued that resources are best focused on wider facilitation of the complex engagement event (AlWaer and Cooper, 2020), leaving little room for resources to support further specialist guidance. SC needs to be able to support the engagement process in terms of the management of roles and responsibilities, rather than the additional burden of specialist support.

6.3 Q3. Technical and Conceptual Advancement

The following question is explored via a combination of participant data and researcher inference across prior discussion points from 6.1 and 6.2, as to what might be possible and/or desirable for near future and longer-term SC-Co. UD.

It is not the purpose or possibility of this research to speculate the full spectrum of change possible through spatial computing, but to attain some key insights as part of building and testing parts of a more holistic picture for Collaborative Urban Design, itself a holistic activity.

Alignment & Socio-Organisation

> *Objective 3a: Advance understanding of socio-organisational, procedural and ethical implications central to urban design professionals and stakeholders' areas of practice: stages, contexts, transdisciplinary working*

Alignment to Aims & Approaches: Concept & Framework of Urban Design

The professionals participating in the research echoed fundamental principles of urban design, as often defined in both practice and academic texts (Foroughmand Araabi, 2016; Urban Design Group, 2019). As, interested in the material properties of urban environment; as interrelated to local cultural context and behaviours as making unique *places* (Carmona, Heath, Tiesdell, 2003). Similarly, UD was felt to be a transdisciplinary, collaborative practice, needing various disciplinary knowledge to navigate, roles, layers, physical and social contextual conditions, and public involvement, adding specific, highly localised insight. Broadly combined, this was believed to improve the cross connection of systems and processes that can be separated by discipline and place-based boundaries; between flexible, strategic design stages, especially early stage, conceptual work, as indicative design products: design vision, conceptual oversight and towards eventual longer-term stewardship. In total, this was felt to influence a more considered but time-context flexibility to the planning and development process (Black and Sonbli, 2019).

For broader and more integrated use in areas of UD, the development of SC applications needs to consider a range of politically influenced processes (Jayne and Ward, 1996; Cuthbert, 2007), some of which are top-down and some bottom-up (Carmona, 2014). For example, with top-down solutions, there may be certain important standards to be met, for example, for planning conditions, climate change, and smart city protocols. The bottom-up process aims to capture diversity, be highly accessible, facilitate localisation, and create unique context-led place responses while managing sensitive political discussions (Dupont *et al.*, 2012). As a spectrum, these are hardly covered by existing standard software, let alone the emergent areas of spatial computing.

Place as a Social Context

"You move from one section of the city to another and see two totally different behaviours."

The various professionals interviewed argued in different ways for a deeper, social contextual understanding than often afforded by the often-formulaic approaches catalysed by politically driven planning protocols and commercial forces. The capturing and understanding of these less tangible social dimensions are almost entirely missing from current publicly available spatial computing applications. They present an area of great importance (Arnstein, 1969) and use-case promise. As human social activities are fundamentally spatially present and arranged (Jacobs, 1961, 1969), as with physical design, there is an alignment to the benefits of SC. As a current example, the immersive capability of SC opens up opportunities for deeply emotive/emotional forms of contextual communication (Felnhofer *et al.*, 2015), such as narrative, combined with mapped social data analysis. Examples such as *The Anne Frank House* (2018) *and Travelling while Black* (2019) give precedent to the ability to place the user in extremely sensitive socio-political scenarios (Carmona, 2014), which can elicit deeper, non-passive engagement in the topics.

Such approaches could be developed via community production, using, for example, new Spatial Video formats (*Spatial Video*, 2023) (untested here) and quick generative AI visualisation of ideas (images, videos, etc.). There is much room for creative exploration and testing here, as ways to align participatory public engagement with broader data collection types, with adaptable levels of input, such as non-direct, crowdsourced data as statistical support to decision making (Jiang and Thill, 2015). Broadly, spatial computing can be conceived to communicate at different scales of influence, from the individual perspective, connecting to strategy, via mapped data, social, geographic, and stewardship management systems (Carmona, 2014; Black and Sonbli, 2019).

For all of this, one expert participant cautioned towards overstatement was presented, in that any technology has limits, and that alignment to politics (Brown et al., 2017): in this case 'of development', can overrule any process. All the Urban design experts discussed explicitly, or in specific examples, the means that in what can be an extensive process of visual, persuasive evidencing, the final decision is often actually made based on local political aims, not broadly considered participatory judgement. Technology can only reinforce a viewpoint (Dovey and Pafka, 2015; Black, 2018), and any representation may never fully match the complexities of a real situation (Seichter and Schnabel, 2005).

Fading novelty and the need for extensively practical uses

Reflection on the range of cases highlights that several participants across the various types of SC showed an initial phase of excitement aligned to the novelty of the spatial format (Nisha, 2019). However, this novelty factor was reduced as time progressed and notably in the later cases undertaken (later 2022 onwards), likely due to participants becoming more familiar and often having some media exposure or experience with AR or VR (popularity of the Meta Quest 2, Fig 70). Even where they had not used them at all or only a little, there was a much more general awareness of various types of AR-VR, particularly the specific limits.

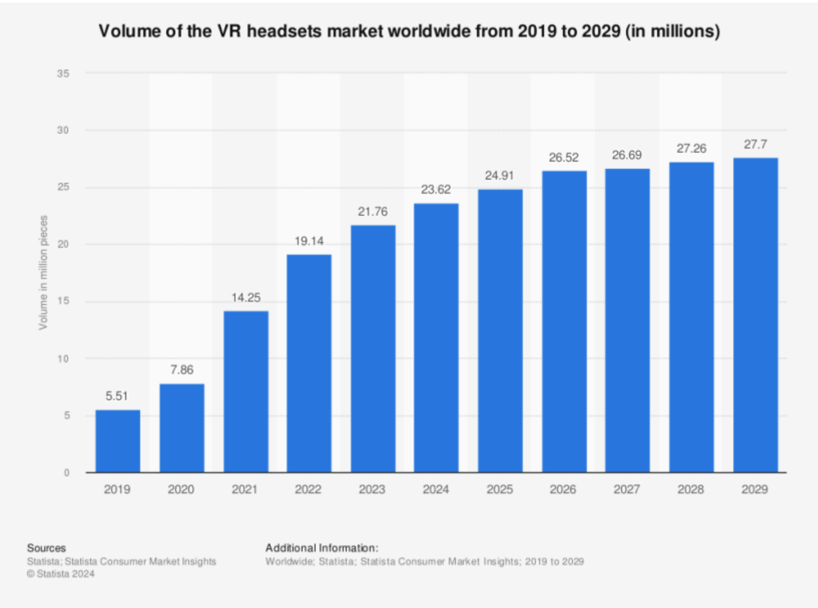


FIGURE 70 - VR HEADSET SALES - START OF PHD ONWARDS

(*GLOBAL: VR HEADSETS VOLUME* 2019-2029, 2024)

Taking advantage of new (old) affordances

Many areas of participant discussion point to the need to develop SC to consider how the affordances of spatial computing might integrate with the affordances of place and in the future, and vice versa. As one of the expert participants discussed, members of the public analyse places simply by the affordances provided to them that they feel are important related to their personal requirements and capabilities. These results suggest a broad aim for SC-CO. UD to handle both a focus on understanding the overall picture (for professionals), and be able to collate and analyse individual narrative information (public knowledge) (Chi, Kang and Wang, 2013), within the context it was formed. This leads to several key considerations.

The first is need for a deeper conception of SC, with a range of applications within and at all the core stages of Urban Design, from Analysis, Pre-Design, Design, Evaluation, Post Design (Black and Sonbli, 2019). This should include a fuller transference of existing 2D affordances into 3D, without rethinking what might now be possible, does not reap the potential benefits or give a clear reason for using SC over existing 2D solutions.

- For example, GE is an (earlier and not updated) conversion of existing software into in its interactions. It does the new broad, intangible cognitive affordances of immersion, but this then is not extended into any new capabilities that 3D immersion might support.

Secondly, there needs a continuing exploration into new affordances that make better, specific use of 3D immersion with the spatial, design-native environment, and taking reference from numerous real-world affordances, beyond the limits of media centric design. In particular, this also needs to ask questions around where and how these elements may start to entirely blend with the physical environment.

Holistic design

SC that is integrated (Ishii *et al.*, 2002) will bring together design layers, to incorporate local social and physical context, professionals discussed as important for thinking beyond the single plot, or building. SC has explored various ways that, if brought together, could provide a 'more than the sum of their parts' benefit. SC to defining ways to communicate to and from local people, provide holistic overview of the design narrative, more effective of shared participant, and wider theory view.

In applied cases, local information could be derived by linking datasets and formats; for example, bringing together crowdsourced GiS mapping with immersive video stories into a platform that moves beyond the limits of Google Earth could bring richness and depth to the design process, community engagement, and planning applications that are currently far from available. It would need management and summarising of data, potential to use Ai, and highlight key trends (local desirables).

Collaborative Adoption

Several participants noted that spatial computing interfaces support interactions that are in many ways closer to pre-digital revolution physical interactions and present a need to unlearn certain expected interactions. With a likely low level of prior experience for many users, particularly in collaborative or participatory approaches, the software and hardware could better support the cognitive transition to new affordances (expected interactions and use) as built-in learning support (Billger, Thuvander and Wästberg, 2016), provided by the SC system design.

Broadly, there was a need to overcome a knowledge gap, both in a general sense of what it is, what it does, what it promises, and specifically for useful applications in urban design. In many situations, judgements were found to be made without appreciation for the wider social or technological context of understanding.

SC is competing with established digital technological standards with highly comparative expectations for highly stable, refined usability.

> *"a missed opportunity for us, was consultation. I would really love to see us using AR, VR, or a combination of both. Consulting on our major development plans…where you've got a lot of change in a particular locality... using it to make those plans and proposals much more accessible to the public."*

While the majority of practitioners and academics considered the technical issues they faced as part of a continual process, students were a lot more divided on an acceptance of these issues. This was demonstrated most clearly by the AR public participation exercise, where three separate groups of students rejected the primary use of AR (after very little testing) and came up with exploratory solutions that removed what they felt to be fundamental limitations to access (though in the process created several other limits). It is interesting to note that some reflection on its actual use at the event, for that, in fact, the AR app was easy to use. In any case, using the system to resolve technical problems is a vital area of focus (Bradecky, 2021).

Future development, Concepts

> *Objective 3b: Conceptualise future applications, based on assessment of current gaps and areas of potential*

Collaborative Facilitation

There appears to be a significant opportunity for SC technology to manage teams and roles. This would mitigate, communicate, and bring parity to what has been described as varying stakeholder abilities (Alrashed *et al.*, 2015; Nyberg, Newman and Westerberg, 2019). This could also be developed to include what has been seen as separate subject area knowledge (transdisciplinary) and team/event management (AlWaer and Cooper, 2020), by stage, process, etc. Such collaborative software could include temporary or instantly switchable roles, such as by types of designers (architect, landscape architect, etc.), including design managers, specialists, stakeholder reviewers, or tutors/educators. SC would facilitate especially via the in-situ overlay of event management information, instruction, highlight, and communicate other users' information – as a social overlay. These roles could also align to specific layers of capability and affordances (advancing and expanding from those discussed in 6.1a - Capabilities. The spatial interface of SC lends itself to such interpersonal facilitation in a spatial context. Integration of spatial Ai could be used to further support such a system, for example, via managing communications, roles, and data. This seems to be a particularly pertinent area for further research to support this gap.

Using animated overlays and guided instructions. Collaborative software could incorporate more communication and guidance for tactile learning, and methods can consider skills onboarding. This could support the user transition to new affordances provided by SC, both in a practical and cognitive sense. SC capability, for example, using an animated illustration in the 3D space from the user's view, could provide an animated trace of gestures to guide users towards a very quick understanding of the physical needs (hand motion, precision). Guidance could also be provided by a help/supporting information system, for example, to collect factual data or find precedent examples, in response to a user's voice commands, position in space, etc.

Location independent

As was evident in the research, even tethered VR generally benefits from a dedicated room setup. It would seem of great benefit in this situation for multiple users to be in the same physical space that is perceptively able to incorporate shared virtual elements (Stanney, 2002; Seichter, 2007b; Sun *et al.*, 2015; Chen *et al.*, 2017; Gironacci, Mc-Call and Tamisier, 2017; Ergun *et al.*, 2019; Hong *et al.*, 2019; Šašinka *et al.*, 2019). Knowing exactly where physical objects and people move alongside dynamic virtual elements is a complex challenge for developers. As soon as the virtual environment starts to overlay large elements, surfaces, and boundaries (walls, floor, large furnishings, etc.), too much would be masked over for safe, shared interaction. Moving towards, hybrid digital-real ('Mixed reality') systems need careful, advanced occlusion, able to adapt and handle a dynamic, changing range of spaces, removing reliance on the dedicated set up currently needed.

Indicative Design, Contextual Information

Building from the above broad position, participants felt that design communication for urban design needed to prioritise illustrative outputs with indicative qualities (English Partnerships, 2000). That is, <u>it is not</u> of resolved, accurate detail, or able to withstand buildable scrutiny. Rather, the aim, as stated, was to focus on representing an indication of the proposal that allows and encourages a design flexibility that understands the long-term nature of built environment processes, such as incorporating the variety of changeable local views and needs, to maintain long-term social wellbeing (Gill and Lange, 2015). For SC development, the continual progress towards integrating more of the similar features and functionality of more established software would provide a strong initial benefit and make SC feel less of a compromised solution. For example, a clear gap for accessible options of SC-CoUD was the limited range and scope/detail of the software options. Providing greater design context information: Mapping and contextual data would help. For example, combining the interactive capability of Arkio with the basic contextual information of Google Earth VR would immediately fill the gap as identified by the research participants, ideally with a little more depth of data, adding maps, and layers, as provided by most standard online mapping. Slightly more advanced GiS features could take this even further, more automated integration of national mapping services (for UK for example, Ordnance Survey, Digimap) to layers of a much wider range of data to support the design process, could be incorporated to reduce the need for additional processing power, or designers' time editing and importing.

Information and Simulation

Going further, as participants discussed, there might be great potential for immersive simulation. While participants explored changing lighting conditions within the modelling software Arkio, due to the limited light rendering and material qualities and simple environment, the benefits of simulating different daylight conditions did not present with the qualities that can alter emotional mood as presented by Felnhofer *et al.* (2015) and Moreau (2013). Attaining a certain level of believability in rendering may be required for this to have a useful effect which requires more fundamental hardware/software advances for accessible devices. There are opportunities for less processing heavy applications, providing data simulation that is lower resolution, but rich in data useful for design, for example, wind, microclimatic simulation using simple graphical, animated overlays.

Participants discussed how digital information could interact with physical entities and structures. Such integration of data and data systems, as principles of BIM, CIM applied to real world locations, principle of information overlay as interactive: e.g. discussed 'tree – how to care for, planting, watering, attached digital info, etc.' This could also be gamified to enhance engagement with the public.

Aligning social and emotional content to geopositioned (GiS layers) aligns to specific locations as a trace of histories and culture. With adoption, could provide crowdsources, could support interactive, data driven, rapid iteration

Professional Alignment, Customisation

As design focused people, participants felt that the SC hardware and operating systems were often quite gaming orientated in approach - though largely testing meta-products, which are game orientated. In terms of practical and stylistic interfaces, options for UX are more appealing to design professionals. As operating systems (broad system environments), there could be layout and capability options to match different types of users beyond gamers, not only in terms of the look and feel, but also in terms of types of use, focus, and expectations, for design professionals, specific end-users, and actions, to match a broader range of user needs (Sanchez-Sepulveda *et al.*, 2019; Park and Stangl, 2020). This approach could further extend towards customised interfaces, facilitating rendering, artistic styles, and effects, aligned to illustrative approaches (not highly realistic), indicative, and aligning to UD requirements.

Shared Communication

Within public participation, students indicated concern over the need to clearly and transparently communicate the actions and intentions of the facilitators, which they felt would not be the case using tablets. As it turned out, it was also true for the other methods. The sharing of such information could be achieved using physical signage, and spatial computing could be animated and/or video-based, as various ways to more directly show the activities to passersby; further away, more publicly, to engage other citizens, walking past, to the benefit of better shared understanding (Alrashed *et al.*, 2015; Gül, Uzun and Halıcı, 2017), engaging beyond the initial co-designers, to observers who may become more engaged.

Though not extensively tested, participants regularly mentioned and assumed an advantage of SC over video calls for remote collaboration, as an awareness (perhaps logical assumption) of the idea that it provides increased "perceptual awareness" (Chowdhury and Hanegraaf, 2022), as an obvious application of immersion, as adding nature added additional means for communication vs. video. Blending between, distances, realities – deal with and handle these transitions very carefully and reduce dissociation effects.

Automatic, Ergonomic Calibration

Regular issues were raised with comfort caused by audio-visual and physical calibration across a variety of participants and settings, reducing the timeframe for use. The wearable technologies unsurprisingly cause the most issues, as many did not know, or could not work out how to adjust the headsets, interpupillary distance (IPD) settings in the headset, echoing reports by Nisha ((2019). And as discussed, this is very hard for someone else (facilitator) currently to do, as they cannot see what you see (how IPD adjustments affect your eyes, or the head strap feels). Within the complexity of running a collaborative event, these kinds of issues divert attention away from various other aspects to consider, design, and event support. On this a huge benefit to the smoothness, would be for systems to be able to intelligently manage calibration to a user, with audio level matching related to room acoustics and automatic eye calibration, adapting the ergonomic setup for each user. These aspects are currently possible, though only on newer, expensive devices which have eye tracking, as 'auto-IPD' (e.g. Vision Pro, Vive Elite, Varjo ('IPD', 2024))

Perception of Hybrid-Real Places

There is also caution regarding the cumulative effect of realistic tactile convergence of SC. This could progress towards a point of increasing difficulty in separating the real from the digital reality (Walz, Gloor and Bebi, 2008; Potts, Jacka and Yee, 2017). We might start to question whether physical is worthy of investment. Perhaps digital elements will make some physical elements cheaper and more adaptable. And our preconceptions and reactions, based on everyday senses, might deceive us, with personal and political alignments, advertised and consumed.

The one reality, search for throughout the enlightenment period, may be increasingly understood not only by multiple cognitive lenses (Bhaskar, 2008; DeLanda, 2019) but also via a multiverse of digital layers. Are all to be believed or are all ideas of fixed reality rejected in their entirety?

> *"Will he not fancy that the shadows which he formerly saw are truer than the objects which are now shown to him?" - the Allegory of the Cave (Plato, 360AD)*

6.4 Summary Reflections

Spatial Computing and Urban ‘Place’

Many earlier studies (chapter 2,3) have established the key benefit of spatial computing as beneficial for conveying scale and immersion in the conditions of place (Koutsabasis *et al.*, 2012), yet few discuss social meaning. Urban place is more than form, or textural qualities, but is a process of change, including layers of cultural nuance (Carmona, Heath, Tiesdell, 2003). Current SC platforms capture this complexity with an uneven mix of attention. For example, the eye-level scale, massing and enclosure read clearly, allowing users to grasp overshadowing or street width in seconds (Koutsabasis *et al.*, 2012). However, the visual layer is often lower-resolution, and lacking real-time environmental cues, such as wind, temperature, sound and so on, which are largely missing, especially from low power optimised, particularly mobile headsets (Alonso *et al.*, 2018).

For virtual environments (VR or otherwise), the depth of social context in the current applications was covered in less depth. Most of the presented scenes and environments relay a frozen, lifeless timeframe. Users did not see the full life of the place, let alone extended timeframes such as project phasing, material decay, or future design adaptations. This echoes prior critiques of the ‘rendered visualisation’, which privileges the perfect ideal, over the longer-term reality. Multi-sensory feedback is also limited. Whilst sight is the main focus, sound was much more limited. Wider senses, as might be relayed by haptics, or scent remain experimental features (not easily accessible), thus reducing potential emotional connection to place (Felnhofer *et al.*, 2015).

Key advances in conceptual application could make significant benefits to representing or integrating with place ahead of and in combination with the steady advances in technical capability. Efficiency gains from gaming technologies could quickly allow for example, enhanced shadows, or wind vectors. Such (contextual) data could be diagrammatically overlaid rather than requiring intensive rendering. In addition, community sourced data sets, such as spatial video or audio, voice-overs could be geo-located, providing deeper narrative, based cultural context. Procedural and animation approaches could provide simulation, to see for example trees mature, materials weather, or local centres come alive with crowds, or events. SC that can blend with existing contexts, would allow a blurring of real and digital elements.

TABLE 19 - LITERATURE VS RESULTS: PLACE

Aspect	Earlier literature	What this study found	Gap level
Environmental realism	Need for real-time data layers (Alonso *et al.*, 2018)	Accessible systems omit sensory cues; wind, sound and temperature, etc.	Significant
Socio-cultural depth	Deeper, individual avatars improve empathy (Hong *et al.*, 2019)	Environments, avatars lack demographic nuance; place memories not included	Significant
Temporal representation	Few references related to SC	Users want phasing and stewardship timelines, largely absent	Significant
Sensory breadth	VR touted as fully immersive (Felnhofer *et al.*, 2015)	Accessible immersion still mostly visual; haptics/scent experimental	Nuanced

Key take-aways

- Geometry is easily solved; meaning is not (significant gap). The idea of 'Place' is complex, multilayered. Real-world conditions this involve much more beyond current SC applications, such as microclimate, local culture and individual narratives, and not least: change through time.
- Power light, conceptual heavy additions - could greatly enhance realism (nuanced gap). 'Easy wins', with low processing cost, such as cultural stories, shadow or wind to deepen experience - diagrams
- Narratives are data (significant gap). Pinning community stories to co-ordinates ties proposals to lived memories.
- Full immersion demands multi-sensory cues (nuanced gap). Haptics, scent and spatial audio needed for full spectrum realism.

From 'Design in Silo' to Spatial-Computing Collaboration

It was expected that spatial computing (SC) would remove disciplinary boundaries by letting everyone work creatively within the same design space (Parjanen, 2012; Fonseca Escudero *et al.*, 2017). However, this study highlighted that whilst co-location is relatively easy, genuine collaboration can be hampered by hidden processes and unbalanced resourcing.

Aligned to this, users' attention was regularly made to focus on individual requirements due to specific technological functions. The research highlights that the path to more collaborative urban design through spatialised digital means is hindered by numerous technical, organisational and cognitive gaps that are yet to be bridged (Parjanen, 2012; Brown *et al.*, 2017). Whilst current AR and VR platforms can co-locate users with virtual objects and spaces, they often still mask the processes in which those users act and interact with each other (Fonseca *et al.*, 2014). The lack of shared affordances, as micro-gestures, menus and controllers act as barriers, reducing the nuanced aspects of 'design studio' (Seichter, 2007a), so reliant on learn-by-doing and watching (Gibbs, 1988). Platform-specific workflows, each with their own compromised design decisions, create limitations, requiring a reliance on certain individuals who act as technical facilitators, reinforcing a specialist–lay divide rather than increasing inclusivity (Nyberg, Newman and Westerberg, 2019; Delgado, Oyedele, Demian, *et al.*, 2020). Organisational access can be variable, creating inconsistent use of spatial hardware, software licences and networking, creating a digital divide in capabilities, reducing convergent practice (Brown *et al.*, 2017).

However, the research also points to clear opportunities to change things. Smooth translation between technical systems and professional mind-sets is slowly reducing the need for mediation (Torres Vega *et al.*, 2020). Increasingly visualised workflows could allow a more calibrated, in-sync multi-user process, where novices could easily learn with rich guidance from the spatial interface and experiencing other users' interactions with rich ecological validity (Krukar and Schultz, 2024), i.e. emotionally nuanced body language, intricate multi-sensory gestures, deep physics and physical properties (construction) with deep tactile feedback (Luigi *et al.*, 2015; M Rose *et al.*, 2015; Moloney *et al.*, 2018; Strunden, 2023). Spatial computing could reduce or even remove design silos if built with greater transparency, parity of access and consistent approaches. Currently though, it presents an impressive mode visualising component parts of an ad-hoc landscape of potentially integrated capabilities.

TABLE 20 – LITERATURE VS RESULTS: COLLABORATION

Aspect	Earlier literature	What this study found	Gap level
Process visibility	Immersive work said to be “intuitive” and to need “no prior training” (Fonseca Escudero *et al.*, 2017)	Users could not see one another’s micro-actions; implied learning was stalled	Significant
Interoperability	Plugins reduce friction (Torres Vega *et al.*, 2020)	Plug-ins help, yet texture loss/scale errors still common when hopping platforms	Nuanced
Expert reliance	SC pitched as democratising (Brown *et al.*, 2017)	Teams still depend on a few “XR translators”; expert–lay divide persists	Significant
Access equity	Cost a “declining barrier” (Delgado, Oyedele, Demian, *et al.*, 2020)	Headsets, licences and networks remain unevenly distributed, shaping who can join	Significant

Key take-aways

1. Co-location did not equal collaboration (significant gap). Hidden micro-actions meant that working side-by-side did not inherently equal shared understanding (Gibbs, 1988).
2. Interoperability issues reduced inclusion (nuanced gap). Intuitive processes are improving but specialist technical guidance remains necessary.
3. Access stalls without shared skill sets (significant gap). Interfaces need to make parity of actions; to shorten learning curves and reduce silo process (which influences silo mindset), collaboration needs a settling in period after technical levelling up.
4. Equity of technical capability is behind ambition (rhetoric) (significant gap). Until equipment and bandwidth are broadly available, silos migrate from traditional approaches.

Spatial Computing Versus Traditional Participatory Methods

Previous studies indicate that spatial computing can be more engaging and better facilitates design process and collaboration (Broschart & Zeile 2015). The evidence presented broadly provides agreement on engagement but adds a warning that the instability of current technology and its rather opaque control can undercut trust in its longer-term use. Traditional engagement methods, such as various types of 2D drawings, scaled models, rely on the public translating drawings into their imagined experience. SC has shown to reduce this cognitive leap, where users can understand an experience instantly (Alrashed et al. 2015). Such free roaming can encourage spontaneous design prototyping, i.e. moving a block or rotating a roof (Broschart & Zeile 2015). The addition of layers of data, e.g. sun, traffic, can appear situated in the space as real-world experience, can reduce the need to interpret the connection between spatial reality and proposals on a plan (Wang & Dunston 2013). This can also reopen participation to remote users, reinstating the sense of shared presence which is lost in video calls (Chowdhury & Hanegraaf 2022).

These benefits are currently fragile. Glitches and discomfort can end a session early. The costs and logistics of setup still present limits to use for less tech savvy groups. Beyond these technical constraints lie wider political and social concerns that need to be considered further. The wow-factor of immersion could easily be used to mask processes that promote inequality of decision making via limited access to information (data layers) or editing capability, or provision in ways that act to cover non-disclosed political intent.

Methods which blend traditional, and SC methods may start to allow ways to bridge these divides. For example, walk-throughs to engage visceral, emotive reactions; aligned to low-tech roundtables for policy detail. Methods needs to capture edits and comments directly aligned to the format used, adding easily accessible, groups and analysed information, e.g. with colour-coded attribution. To support quick parity of users, quick warm-up sessions are required to level digital literacy.

TABLE 21 - LITERATURE VS RESULTS: SC VS TRADITIONAL

Aspect	Earlier literature	What this study found	Gap level
Cognitive leap	SC makes scale obvious (Alrashed et al. 2015)	Participants indeed grasp height/shade quickly	*confirmation*
Power balance	Immersion framed as inherently empowering (Arnstein-style rhetoric)	Editing rights and data provenance were often hidden; directing power to stay top-down, or discipline focused	Significant
Technical stability	Few studies detail dropouts	Glitches and discomfort still derail sessions and trust	Significant
Blended methods	Little current guidance on hybrid workflows	Whole design process workflow required SC to be combined with traditional methods across various stages and for various outputs	Nuanced

Key take-aways

- Visual understanding levels the playing field for discussion (confirming prior). People debate substance, not symbolism.
- Transparency is needed for participatory use (significant gap). History logs of edits and open data will open access and avoid top-down only processes.
- Tech reliability shapes trust (significant gap). Glitches can quickly undo initial interest and ongoing engagement.
- SC still augments rather than replaces traditional tools (nuanced gap). A layered workflow is required to turn 'wow factor' into serious engagement, and deep benefits to design decisions.

6.5 Methodological Limitations

> *"You can choose from a myriad of methodological brackets which will highlight some things and leave other things in the shade." Stones, R (Archer* et al., *1999)*

The following section reports the key research limitations and related mitigation. This is in terms of both practical and conceptual ideas that influence its implementation. Within the context of the still emergent area of knowledge, and methodically experimental. The thematic areas discussed below are not only limitations of the research methods but are also expanded by the emergent nature of spatial computing technologies. The methods were developed within the research timeline and should continue to be iterated in future research.

TABLE 22 – LIMITATIONS

LIMITATION	MITIGATION
Cases and Participants	
A limited number of cases were accessible, with specific mix of participant types.	Events responded to real-world conditions of how projects come about, by its nature need to accept lack of some control. The events were all negotiated with collaborations, support systems. Organising and designing the events had built in approach to maximise mix of participants, alignment to practice, themes. Additionally, the events shone light on gaps that were previously not known. Ideas were iterated between each.
Critical realist analysis ideally untaken by multiple researchers, to consider perspectives, gaps of individual.	Mitigated with large participant types, group mixes. The mix of participants sought a range of views, from different areas and levels of understanding, as well as the evaluation in-context.
Research engaged with practice participants, but could not capture live collaboration embedded in practice, with and from wider range of experts Student participants, present limited pool: age, privilege, limited knowledge to deeply evaluate	Attaining live testing in practice is challenging due to the commercially driven/time-resource limited nature of practice. Multiple captures, reflecting on past, real experience brought benefits to experience being independent of the research, entirely 'real-world'. Students are a representation of wider society as interested/engaged enough to be useful for research (generally speaking), especially at the host university (Birmingham City University) are diverse in terms of demographic, and somewhat of age too (e.g. mature students). Also, students are still learning – so bring variety of and new, conceptual ideas, misconceptions, etc. and represent future of practice – as useful to test research aims / assumptions.

Technology	
Access to 'spatial computing' resources, equipment, software, space, advice. - adding 'other' computing to XR has very limited current availability, practical options.	The researcher monitored opportunities to acquire access to equipment, which has organisational limits (also part of the research - limit to appreciating further limit). Specialists participated in interviews and events. Unique opportunities were crafted by the research, using new facilities and multiple headsets, was innovative.
Technological knowledge and skill of facilitators, participants	A limit, also a point of research. Use of self-reflection, acknowledging and discussing these limits with participants.
Data capture / processing	
Complex events could not capture all conversations, limits to audio capture devices. Some data opportunities lost some indecipherable, audio capture in different environments challenging, especially outdoors public, echo, many people speaking, devices not capturing, for different technical reasons.	Multiple devices were used, phone, laptop and in-headset capture of audio-visual info. Specialist microphones used. Not possible to completely resolve in collaborative real-world settings. Technical limitations of devices - also part of research conclusions (audio issues in headsets)
Difficult management of large data set. Overwhelming amount of data, and different types. Likely some potentially useful data has been missed.	The use of automated transcription (Google, Microsoft) helped in processing data, though not perfect created some additional. NVivo and Excel used for various stages of coding, open to categorised (as grounded theory).
Evaluation methods	
Thematic analysis can mask depth of understanding, nuance of participant context, meaning and social relationships: hence, is challenging to be certain of underlying meaning of responses.	As much as possible, data came from open, participant-led discussion, not direct questions, often in context (e.g. Using equipment), creating a relaxed but professional environment for reflection. Due to the emergent nature of research aims, strategic understanding was preferred over nuance. Multiple lenses and viewpoints and types of data were considered. The outcomes set the scene for future research to understand more depth can be applied into the specific areas highlighted here.

7 CONCLUSION

This final chapter summarises the contribution this research has brought to our knowledge on the use of spatial computing for Co. Urban Design, detailing the key implications for areas of practice, stakeholders, spatial computing developers, and researchers, including pertinent areas for further research.

7.1 Contribution

Aims, Gap(s)

With much development over the last decade, researchers interested in applying spatial computing technologies to urban design processes have often hoped for or claimed revolutionary potential (*spatial computing = Extended Reality {Augmented-Mixed-Virtual Reality} + 'other computing').

Many papers have reported on the success of specifically developed applications, judging that the practical benefits of integrating digital workflows (back) into our spatial world will surely lead to a more transparent process for everyone: better collaboration and more participatory equity, the breakdown of barriers, the opening of silos, and where we might *finally* see designers, planners, *and the public.* fully understand one another. Towards a perfect design process?

Perhaps…

This study looked to '*Investigate the reciprocal relationship between Collaborative Urban Design (Co-UD) and spatial computing (SC) methods related to areas of real-world practice' (Aim 1)*. And to '*Analyse how SC tools might influence the effectiveness of Collaborative Urban Design, currently and in the future' (Aim 2)*.

Contribution

The research brings together various technological, cognitive, and social considerations to provide a strategic overview of the often disparate and varyingly applied types, formats, and values associated with spatial computing that might be of use in Urban Design. Looking at this broad remit, the research adds to a better understanding of the real-world practical impacts on the design process and outputs, including underlying social and cognitive influences in relation to collaborative decision-making. Combined, this adds to the emergent picture of practical applications. This also points to future directions to better align spatial computing applications to urban design requirements.

Spatial computing technology holds enormous promise. Overlaying digital content in our spatial view is in effect quite a simple idea that looks like magic. As shown here, defining a useful application is much more complex in practice. Alternatively, if stated more hopefully, it appears to be more complex but could see increasingly quick resolutions if adopted more fully. These benefits have the potential to be fundamentally transformative and unique to many areas of urban design and wider built environment practice.

However, many challenges still need to be overcome. Some of these challenges sit on the surface, some are much deeper, and some will not be fully understood until we get closer to them following the resolution of earlier problems. Some of these challenges are technical, but many more are cognitive, social, and organisational (and much less explored). Resolving these less tangible issues is a complex task that will continue alongside hardware development.

The main contribution of this research is the greater illumination of a diverse landscape, which has some structure, many emergent properties and variable effects. This conclusion highlights key areas of current use and potential development, but also many limitations that need to be overcome, several minor and some significant. Finally, this points to a potential future where digital information is not separated on 2D screens but can be anywhere in our shared space. For that (inevitability?) we require much deeper thinking about what new opportunities are afforded and how these relate to political and ethical considerations that are not yet fully appreciated.

7.2 Practical Implications

> *"it's really important to acknowledge that it's not a question that can be answered. It is a question that has to be brought into common conversation, that we all need to be talking about all the time. And what you ask today will be different in five years and ten years' time because the technology, the way we're using it…the way our brains are adapting and responding to it, that's changing as well" (Participant, Lecturer Visual Communication)*

Implications for Professionals with Urban Design interest

Near-future design studios may look quite different. It may be problematic to envisage an office setup where everyone is wearing a 'clunky looking' headset, wearing heavy devices all day, that are not quite accessible enough and can be isolating rather than more collaborative. However, the situation is increasingly starting to feel very different, with each generation of spatial computing coming with increasing power, less obtrusive, more ergonomic design, more diversly capable software, and facilitating more social and digital integration with reality. As soon as the benefits of SC significantly outweigh technical issues, these devices are likely to disrupt various aspects of how designers choose to work.

The use of AR-VR is often seen in terms of specific practice applications (for example, VR to show the end product to a client, perhaps design review), and there is value in increasingly thinking about a broader, more integrated, and holistic capability. The term 'spatial computing' as used here *(or equivalent – 'to be confirmed'…)* is intended to acknowledge and promote discussion on the potential for '<u>Any</u>' computing to become Spatial; that is, integration of the vast range of digital possibilities into our spatial realm/ personal view of the world. Though masked by some significant current limitations, there is an open spectrum for integration of any existing and future computing capabilities, including new methods that might only be made available by the direct spatial communication format of SC.

This situation is far from being realised. There is a need for those interested in urban design, including related disciplines (planning, architecture, landscape, etc.), to create a vision for what spatial computing (SC) should look like. Currently, there are very large gaps (some total absences) in the provision of potential SC types. There is much scope to create useful spatially integrated solutions that incorporate the various layers and nuances of urban design. For example, to support:

Accessible, engaging experiences, that are more immersive (narrative) and able to give an appreciation of local context and design ideas. E.g. lightweight apps that focus on contextual and interactive gains, such as storytelling, place specific content, leading on integration with the real (augmented/mixed).

Conceptual, indicative work, to support quick prototyping, testing potential; non-definite design ideas, as matches strategic, framework urban design approaches. E.g. treat/visualise design objects as provisional ('sketch'), show quick animations of future growth pattern of trees, provide ability to share and iterate with logged states.

Collaborative processes, that facilitate types of early, publicly engaged, non-tokenistic public engagement. E.g. illustrate and manage process, session logs/project timeline, show the how, share through ghosted cursors, animate other commands and gestures.

Navigation and management related to UD work stages, considering political, policy and financial requirements. This should include provision for early design stages, through from site procurement and analysis, planning. This may also allow and connect to rich contextual data sets on social and physical context data, as well as allowing highly accessible modes for upskilling and training of the systems for the range of stakeholder capabilities. E.g. roles and responsibilities: novice, practitioner, expert with aligns UX design, capabilities and level of guidance, align plugins and data layers to stages: site procurement/analysis, conceptual vision, post occupancy stewardship

Open conceptual exploration of potential future areas yet untested, or unexplored, alongside reflective, ethical critique, rather than relying too heavily on simply porting established types into SC.

Implications for members of the Public, Stakeholders, Community Groups

Spatial computing is opening up ways for public and non-expert stakeholders to more easily engage in design process, as a direct interaction in 3D space (spatial). Owing to the visual nature of design, one of the most challenging areas for those not trained or experienced in design is to fully understand what is being proposed. Whilst there is need for professionals to represent design ideas in ways that can be measured, scaled or that otherwise summarise an overall picture of ideas in one image. These can be quite difficult to decipher without training. The standard approaches (e.g. plans and sections) that are often used in design communication can be abstract from our natural understanding of the world: as a 3d space that we can see and move through. Similarly, different professionals use different methods, which can add to creating a complex process for full appreciation. This has been recognised as a potential issue that reduces access for members of the public and non-experts. In addition to this, the standard process is typically decided on by the governing body and realised by an external design team. As such, design is typically influenced by governments and experts, without deeper consideration of local points of view, and with strong suggestions on how they might think about a design project or place.

Spatial computing is increasingly offering a solution that brings design communication ('back') into our 3d view of the world, as a form of communication that we can directly see and experience. This mixes digital content with our natural perception of reality, seeing, and hearing in space, and therefore offers ways to radically remove some of the barriers caused by the commonly used but often quite abstract methods. As shown here, the use of spatial computing is far from fully established now, but its applications are potentially limitless and we expect to see rapid development and opening up of software options, that can in various ways open up community voice to planning, design, and development processes. spatial computing options are the most accessible they have even been, available with relatively cheap, mobile devices, with increasing stability and quality, which have seen great improvement since the research began and seem to be rapidly improving further for each hardware iteration (i.e. each year or two). Alongside more adoption, we will likely see the opening of many more hardware options that might facilitate more open systems, or at least more options that better align with societal, governmental, participatory aims, rather than the specific media-driven aims of corporate entities.

Spatial computing is still somewhat emergent, and many more options are expected to become available. Community groups and stakeholders need to engage in this process to shape a vision for spatial computing (SC) that fills some of the large gaps in provision for encouraging engagement and making it more accessible. There is a huge scope to bring further uses that could be of deep benefit to promoting community input into neighbourhoods.

Current suggestions:

Over the time of this PhD, implementing SC has become far easier, with a reduced need for advanced specialist knowledge, such as game engine development and coding. These greater opportunities are opened for implementing multiuser collaborative SC, which will still be best supported through having individuals who are dedicated to the technical role of setup and resolution by familiarity with the specific choice of systems being used (including networking, space), to navigate the relatively minor but reoccurring technical considerations and issues that are likely to occur.

Hardware: improvement of cameras, has opened options for mixed reality, (passthrough). Low-cost devices are now relatively stable and offer many connectivity options (e.g. Meta Quest and Pico Neo). Similarly, whilst still limited software is becoming increasingly available in native mobile formats (headsets or phones). For example, the software used in this research has already been developed since documented testing, improved stability, and capability, for example,

- 3D modelling, multiuser collaborative design, for example, Arkio (2023) – can do live, outdoor mixed realty design
- Mapping – e.g. EarthQuest (2024)–based on Google Earth VR, but options for navigation, smoother transitions between scales.

Implications for Hardware / Software Developers

For the spatial design fields of urban design, architecture, and landscape architecture, a key aim should be to bring the level of interactive digital capabilities of VR, but place this as overlay in the real world (AR-MR) in ways that allow co-design within that shared digital-real space. Even as the range of spatial hardware devices improves, such as high-end mobile devices (Patel, 2024) (e.g. Apple Vision Pro), the significant limitations of this study remain. This presents an uncertainty for those who want to invest in equipment, and this becomes even more of a challenge for collaborative work, where multiple devices are needed. This is particularly the case for typically lower budget, community-driven, or smaller practice organisations. A large investment for uncertain benefits indicates a current suitability to specialist hire and support arrangements, rather than outright purchase.

- Alignment of spatial computing to Urban design, Collaborative practice
- Gap in the market, seeing VR and AR as mostly for gaming, media, which is only partially filled.
- Different markets within, even different UX approaches, professionals
- Stakeholders: public, more stripped back, different

It might be assumed that people will give the benefit of doubt to slight technical problems of SC as it is so immediately impressive and for most offers' great potential. While enthusiasts and specialists of SC may have the confidence or willingness to give the benefit of doubt to minor errors, the various participants in these cases presented regularly did not. Rather, their first impressions were often fundamental and quick judgements, which seemed to become lasting ones. Several of the action-led cases presented a recurring need to break preconceptions and make quick judgements. First impressions and preconceptions of SC were shown to be important, and care is needed to ensure the quality of experience for those new to it. People were shown to make quick judgements, with broad assumptions based on narrow, unreliable assessment that might cement their view and reduce likelihood to engage further. In real-world scenarios, typical group collaboration may be made up of a mix of skill and level of interest in SC, with a likely far lower tolerance to anything going wrong and with immediate comparison to other highly established, highly stable areas of computing.

Align UD specific Capabilities and Affordances

There is much scope to align to areas of Urban Design as an overarching field, which aims to better integrate processes and outcomes that span the disciplines that deal with urban places. Relative to various layers of UD consideration, the range of aligned spatial computing capabilities is still very limited, both in scope and more so in the intricate affordances that make refined, professionally useful software. Whilst it has not been the intent or scope of this research to suggest how to go about technical improvements, several key points and suggestions are included – see discussion chapter, 6.1, 6.3. These particularly need to consider the following.

Integrated layers of data and capabilities could benefit multiple related disciplines: Architecture/Landscape Architecture, Planning. This should connect to wider studies in socioeconomics and various areas beyond. To incorporate or connect to the range of deep capabilities present in established design formats, such as city modelling/simulation, online libraries with contextual (national, internation policy, standardisation), and professional specifications.

OS, user interface (UX) design needs to match design professionals' expectations, for overall style, practical capability, and specific affordances that support the design process. Aligned to those who are working with and taking their main design cues from the real world, not gaming media. This should enhance participatory facilitation and management in support of collaboration, roles and responsibilities, with the potential for Ai to integrate and automate these processes.

Discipline alignment is not simply an exercise of technical improvements, but needs to appreciate a deeper, more holistic view of the broader, extensive and complex social, collaborative dimensions that are critical to urban design.

The capability to produce conceptual work quickly, as opposed to time consuming 3d modelling would allow focus on the earliest stages of the development process, to quickly explore ideas (design precedent), incorporate and manage political discussion, encourage balance, and parity in public engagement. This could include many social and design process considerations through various stages of Planning and Urban Design, from public input to site analysis, through to post-build site stewardship.

Key Technical improvements for Multiuser Collaborative work and Urban Design

Prioritise technical stability as environmental immersion needs failsafe mechanism, such as auto-shuts off and communication to make the user aware of major errors, to avoid stress and issues of cognitive dissidence for the user.

Provide fundamental design interaction capabilities of other software need to be made available, adapted for SC. This should include the range of integrated functionality, including for example, better layer management, precise snapping, measuring and drawing, to distances and axis.

Give better feedback to users, especially tactile and visual interactions, as signifiers with relation to specific affordances that are available.

Automatically facilitate, ergonomic, multiuser adjustments, generally and especially for collaborative situations, for example, such as auto calibration of acoustic levels according to physical space, acoustics (room correction). Or of similar importance, automatic/automated (and quick) inter pupillary adjustments (IPD) adjustment.

Improved comfort and ergonomic integration of hardware, to include support for increasingly refined tactile interaction: gestures and design manipulation by hand and body.

Continue to reduce the learning curve and embedded Knowledge. Learning of SC systems seems to be quicker but needs to reduce the gap between software affordances and variable user capacities. This cannot reply solely on embedded appreciation of spatial controls, such as skills in particular types of video gaming. Rather, more skills need to be based on real world skills, such as hand-eye coordination, or more specifically the full skillsets required for types of physical construction, art, or hand-drawing.

See chapter 6.1 for further depth.

7.3 Further Research & Implications

Implications for Researchers

Spatial computing presents various, potentially transformative, and/or disruptive impacts on Urban Design practices and places. In some ways, this potential refocuses design to modes more familiar to pre-computing. As SC develops, there are open opportunities to align with networked Ai and GiS levels of data, alongside increasing integration and blurring with users' spatial perception of the world. The cutting edge of graphics now will likely be mobile compatible, relatively soon, offering increasingly realistic and believable digital layers of design, blurring our understanding of the digitally imagined and the real. This raises questions about the future perception and nature of reality itself, and of what will become of place. Will it become an increasingly hybrid mix of physical-social and digital reality (which it largely already is)?

The technical capabilities of current digital work are likely to be converted, but there is much space to better understand which capabilities and affordances spatial communications might offer, and how best to implement them. The integration of digital work spatially will likely start to take design back into our spatial frame in ways that are more akin to pre-digital working while retaining the benefits that digital brings to the table in production efficiency and range of capability. Such shared three-dimensional communication might enhance access to design ideas, but its effectiveness will need to be stress tested and refined under a large range of conditions. However, there are also several significant caveats to this, of which many have been under-discussed and sit within the realm of hopeful optimism. Much of the potential is awaiting realisation, much more feels vague, and offers multiple areas for conceptualisation in practically aligned research.

There are also many social and ethical questions that need to be discussed, not just what can we do, but what should we do? - How would digital overlay impact social dynamics? Will we require real materiality? Will people have or want their own overlay of reality? Will we see and interact differently with each other? Etc. What becomes of Urban Design, the Urban Designer, Architect, Planner, etc. Currently, this technology seems to be progressing ahead of the discussion.

> *"What they lacked was a Concrete Utopia that delineated, embodied and combined the various possibilities they sought in a realizable manner" (Archer, 2019)*

Further Technological testing / conceptualisation

In this still somewhat emergent area of spatial computing, repeated research approaches are needed following key technological advances. Particularly when/if adoption is increased in practice, to provide practice-situated cases. The latest technological iterations (generations) have already been technically improved over those used in this research. Cheaper consumer headsets were used, which could be improved with increased budget, though over the next 5-10 years, the capability and adoption in practice will likely look very different.

Collaborative research between a range of urban design stakeholders and experts with computing and game design specialists, could explore the integration of wider and other computing aspects (for true SC). Of particular interest, might be:

Design conceptualisation, using Ai supported user interfaces for example in generative images/videos for real-time audio-visual collaborative ideation, as prototyping.

Collaborative facilitation, through integration of Ai large language models (LLMs) or Ai agents have the potential to provide digital facilitation of event management, roles and responsibilities, an wider social actions.

Learning and navigation of SC systems, via animated instruction of digital physics, interaction and gestures

Intelligent parametric digital modelling could aid in the fluid production and editing of models, allowing quick exchange of ideas between collaborations.

Collaborative set-up of technical systems for blended, virtual-real collaborative environments, such as for automatic audio and visual calibrations – e.g. room correction, etc, spatial alignment, integration of real and virtual objects (e.g. advanced occlusion).

Increase data supported decisions - better integration with information modelling: Building and City Information Modelling (BIM/CIM), potentially aligned to placed based Smart City Data and systems, as well as Geographical Information Systems (GiS), and drone technology, to support decision making, with much larger, more accessible datasets.

Explore new opportunities afforded by spatialisation of computing, such as spatial positional analytics - positional tracking, related to emotional, narrative, etc, or perspective analytics, interaction and gesture, visual tracking of user's interactions (i.e. advanced from the video analysis used in this study)

Further Cases and Participants

Continued studies in new and alternative place-based and social-economic contexts, including international locations, with specific demographics, areas of society, testing specific challenges. It would also be interesting to compare differences further and more directly compare the impact of SC by level and type of background experience, for example, discipline or stakeholder.

Quantitative data to further evidence emergent inferences, provide weighting, and feeling for the importance of certain categories, of benefit/drawbacks in different places and types of organisations.

Multi-team discipline UD research, with researchers from the different backgrounds relating to UD, e.g. with Planning, Design, Social, Economics expertise. This could also look to undertake similar methods in practice environments, considering how to navigate the conflicting, competitive nature environment vs the more open nature of academic research. Long term trust is needed to review organisational and inter-organisational systems and processes, via strong practice-academia relationships.

Further Evaluation Methods

Future research could explore more details of context and participants' intended or hidden meanings, and deeper appreciation of their personal, demographic context.

Deeper social-organisational, contextual studies to deeply appreciate specific mechanisms. In the context of transdisciplinary collaborative, live design projects, with novel technologies applied, it has been difficult to decipher with certainty the relationship between a very diverse range of numerous layers, for example, levels of engagement, capacities, and potential social-organisational influences. Further study in this way, and by categories, such as defined by Gül *et al.* (Gül *et al.*, 2013), could be compared across different types of spatial and non-spatial use cases. This could be applied to pedagogy, building on various studies, particularly by Fonseca et al., (2014; 2015; 2017). However, similar approaches could be undertaken to explore the impact on practice and/or stakeholder contexts, if institutional access can be agreed (i.e. academia-practice collaboration, knowledge transfer, etc.).

Discourse Analysis to better appreciate social, emotional context of participant responses, by capturing data within cases. Participants regularly spoke in ways or used words which represent or relate to certain cultural meanings and expectations. This would require an in-depth focus on case conditions and looking into deeper expected meaning. It could then provide a way to more deeply understand the underlying social power dynamics that are present in different types of practitioners and stakeholders, as well as their level of experience. For example, the use of the word" consultation' was common among the participants in this research. Do participants personally align to its meaning or use it because of its prevalence (peer use)? Is this merely a local thing? Does it represent something in UK planning-design, and/or wider culture, relating to ideas of democracy? How would this impact their appreciation of spatial computing design, affordances, etc.?

7.4 Final Statement

This research sits on the cusp of a change towards increasingly accessible and capable applications of spatial computing for which technical issues are solved, potentials are opened, with increasing adoption and widespread embedded knowledge. There is a need for those involved in urban design activity to think ahead on what is ultimately desirable for urban design process and for urban places. We need to participate with cautious optimism towards developing a vast range of favourable opportunities.

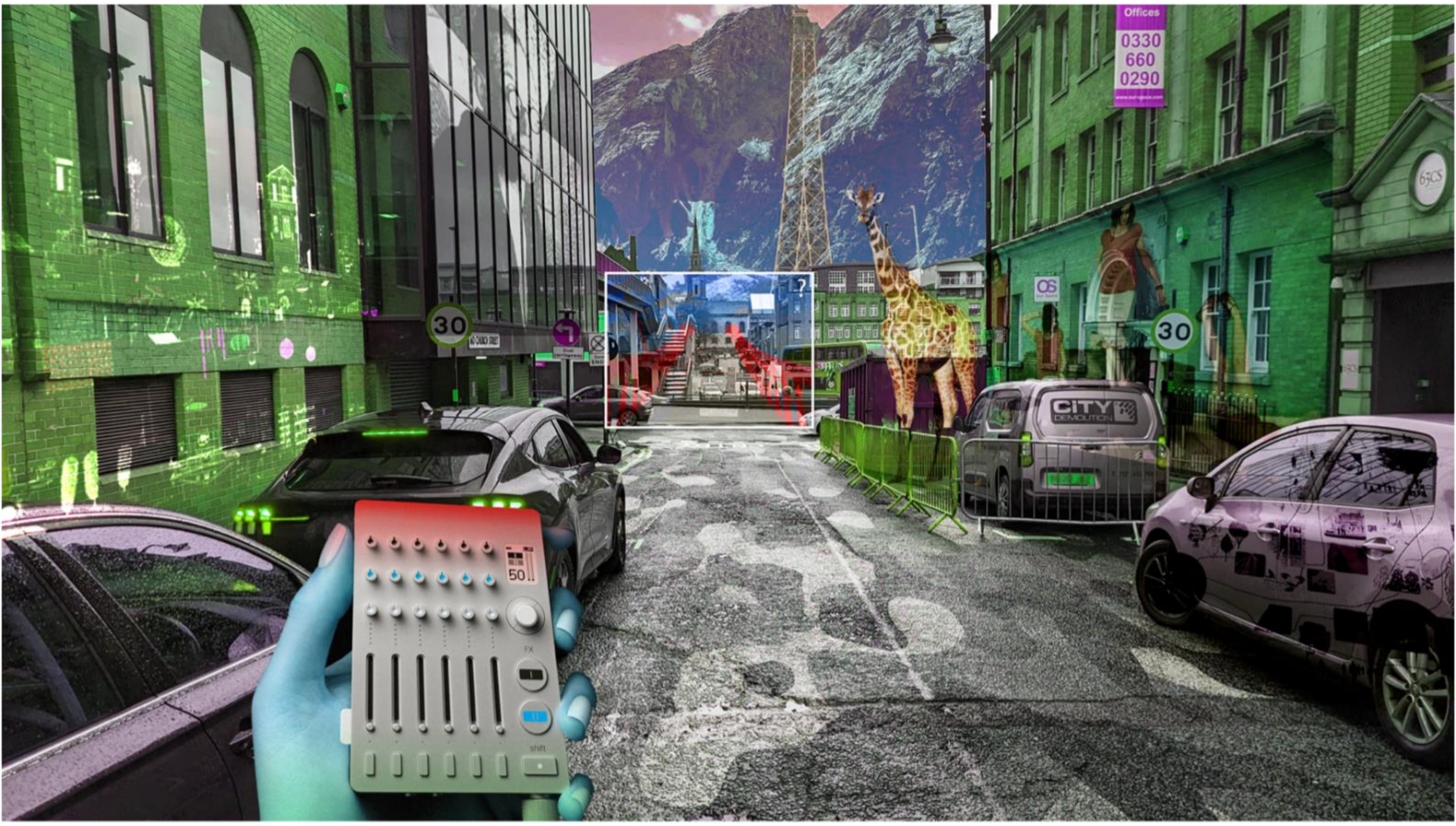


FIGURE 71 - CONCEPTUAL PHOTOMONTAGE, SPATIAL OVERLAY, WITH ASSEMBLAGE 'CONTROL KNOBS' (DELANDA, 2019) - PERSONALISED UX OVERLAY (MADE FOR FUTURE 'COLAB' - ADVENTURES IN HYBRID PLACES 2025), AUTHOR

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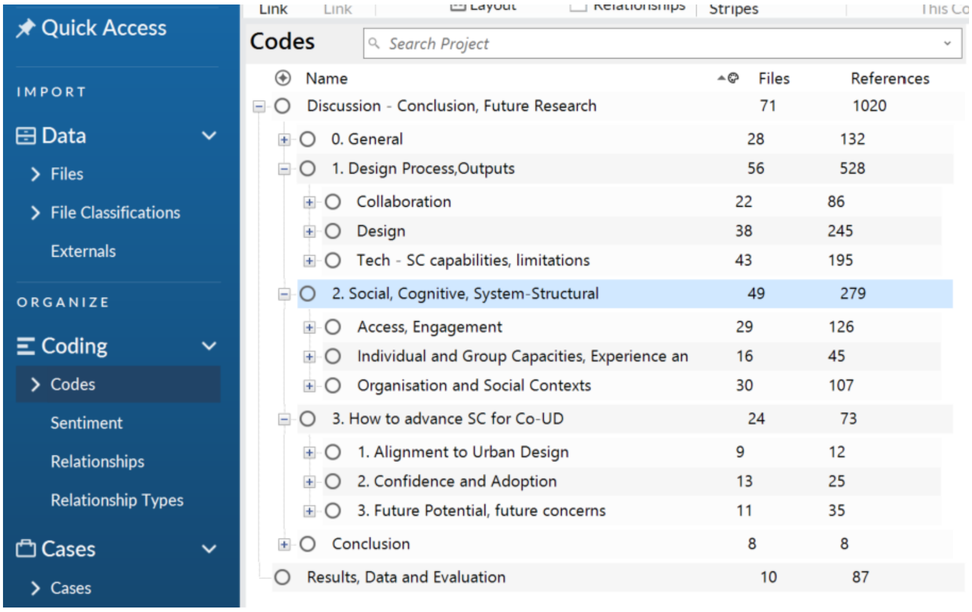
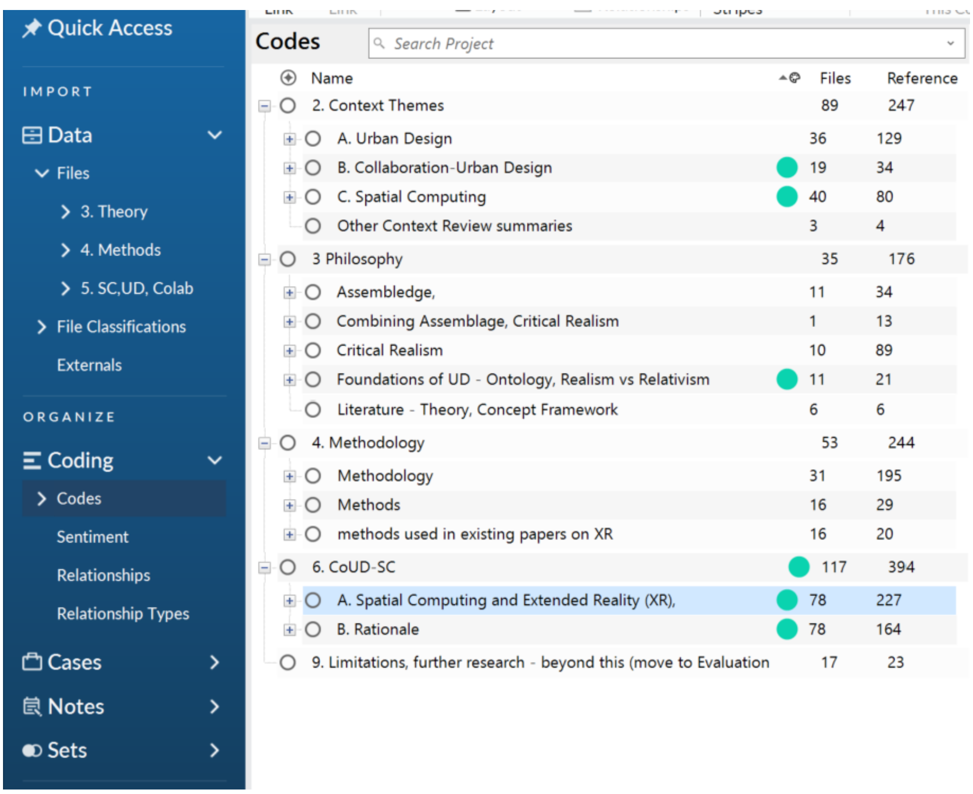
9 APPENDIX

Secondary Coding NVivo



Primary Codes in Nvivo



Summarised Data Set - Primary Codes and Interpretation

Exported to excel from Nvivo and analysed further, with comments and inferences. See separate document:

'PhD_LHughes_SC-Co.UD 24.10 Appendix Coding - final stage'.pdf