New Knowledge for Built Environments: Exploring Urban Design from Socio-technical System Perspectives

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Abstract. This paper details the value in exploring, applying and disseminating Human Factors methods in Urban Planning and Design. This innovative research recognises that from a paradigm perspective there are similarities between the challenges faced in both disciplines. The authors have applied Cognitive Work Analysis (CWA) to explore a range of built environment issues. The findings have allowed for a clearer interpretation of the systems relationships within urban design contexts – from the functional purposes, to the important objects contained within them. This paper highlights the applications, and discusses the implications for future research and practice. It is concluded that the research contributes to a better understanding of the interdependencies between the designs, user experience and engineering requirements of key urban design projects.

Keywords: Human factors · Sociotechnical systems · Urban planning · Urban design · Sociotechnical urbanism

1 Introduction

This innovative research recognises there are similarities between the challenges faced in both Human Factors and Urban Planning and Design. At a simplistic level the issues found in both areas are one and the same – the design of the environment brings about emergent behaviours that in some cases are not optimal. This paper explores the correlations between the disciplines by reflecting on urban design in consideration of the descriptions of Human Factors challenges. Such inquiries are often described as humans and systems not behaving as they were expected to; problems which impact overall system performance; and often issues that have been resistant to a range of an ongoing technical interventions [1]. The same is true for many of the challenges in urban planning and design, including crime prevention and safe cities; the prioritisation of walkable and cycleable neighbourhoods; or the design and implementation of enduring, accessible and attractive public open space.

In this paper the potential for Human Factors to inform Urban Planning and Design is demonstrated via applications of Cognitive Work Analysis (CWA) in the urban design context. CWA [2] is a systems analysis and design framework that is used to

identify the constraints imposed on activities and then to design new systems that better support the activities of interest. To date CWA has been used in a range of design activities in various domains, including defence, process control, disaster management, and road safety [3]; however, it has not yet been applied in an urban planning context. Through the analysis of case study urban areas, this research provides a means to understand the multidisciplinary requirements for establishing urban form which supports our cities as places for people.

This paper first provides an overview of some of the key planning & design challenges; second it outlines some of the interrelationships between human factors, sociotechnical systems and urban planning and design; third it discusses the use of CWA and concludes by detailing two case study applications.

2 New Knowledge for Built Environments

We need new ways of understanding our built environments. Urbanization and development is quickening on a global scale. In 1800 2 % of the population lived in urban centers, in 2014 it is 54 %, and in 2050 it is likely to be closer to 65 % [4]. United Nations projections suggest at that time there will be 6.5 billion people living in cities. Currently there are 1.5 million people moving to urban areas every week. Globally, the accommodation and support infrastructures cannot physically be built fast enough. There is an urgency to understand and plan for the ways in which we want to live in urban communities.

For new urban development the ‘business as usual’ approach of continued peripheral expansion is neither sustainable from a resource perspective, nor enduring from a community perspective. We need to make more efficient use of the cities and towns we currently have. For example, how can we value add to existing transport corridors, and how can we support mixed use, higher density living with current city footprints?

There have been a range of efforts which seek to achieve these aims – new urbanism; transit orientated developments; smart growth; knowledge cities – all with some traction for a complex problem. This paper contends that Sociotechnical Systems and Human Factors approaches offer us new perspectives on the planning and design of our cities and towns.

In this research urban planning and design are considered as such: *urban planning* may be defined as the urban and regional policy and strategic intent for both built and natural environments within a particular area; often dealing with the use and management of land and buildings. While *urban design* is considered here as the actualization of planning objectives at the human and neighborhood scale. Together they consider broad scale strategic planning, to local plans, and down to detailed design outcomes.

2.1 Urban Planning and Design – A Complex and Fragmented System

Urban centers, their planning and design are complex and often fragmented systems. Planning must deal with a range of significant issues at a variety of spatial and temporal

scales. For example matters relating to transport, water or even the economy are important from the micro to the macro as they cut across regulatory and spatial systems [5].

Urban planning and design involves an increasing range of stakeholders and finance from both the public and private sector. Planning and design are big business and expensive pursuits which require commitment for results over the long term – often in the face of competing public and private sector priorities [6].

Complexity also arises from that fact that planning and design are about vision. They are both intended as legacies of long term consultation and should be representative of their communities. However they are often influenced by fad, fortune and politics; resulting in built and natural environments that are not fit for purpose.

2.2 A New Approach

The complex systems underpinning urban planning and design need to be viewed as one complex, interacting system. Urban planning and design need ways in which decision-makers can see the value in commitment, they can see their places in the puzzle, and indeed that their priorities are reflected, considered and optimized. All stakeholders at all levels must be able to recognize the consequences of choices and trade-offs, and be assisted in understanding the interdependencies and possibilities of better coordination and cooperation.

More specifically, urban environments can be thought of as sociotechnical systems (STS). When considering the purpose and priority of STS is the optimization of people, technology and environments [7], there are lessons to be learned from these approaches. Indeed, this paper would argue that the optimization of those key elements are on many levels the goals of effective urban planning and design.

STS Approaches. Key national and international researchers in STS identify that it has some key features [7]. Importantly that these approaches consider: 1. Safety and adverse events (e.g. accidents) as emergent properties; 2. Systems and component performance is variable; and 3. Systems are dynamic; yet hierarchical structures.

These considerations are immediately applicable in the priorities we should be understanding for our urban planning and design of cities and towns. Safety; understanding that city performance is variable and dynamic; and that cities are systems within which the hierarchy of scale, from site to strategic is imperative.

Another important parallel is the acknowledgement that neither Human Factors nor Urban Planning disciplines resides exclusively in engineering, nor are they the pure domain of social scientists. Both require careful consideration and understanding of the range and scale of the objective technical parameters. Both are necessarily concerned with engineering, metrics and exacting tolerances.

From the social science perspective both must consider significant personal experience, behavioral and subjective interfaces. That is the inevitable understanding of people, their needs and their impacts with one another and with built and natural environments around them.

The key is that the discipline of Human Factors has already considered ways of including multiple perspectives and the input from a range of disciplines and decision

makers [1]. Planning continues to struggle with this complexity and in the same urban environments, architects, engineers, planners, landscape architects and elected members all continue to work largely in silos.

3 Cognitive Work Analysis

The CWA framework comprises five interrelated phases: 1. Work Domain Analysis; 2. Control Task Analysis; 3. Strategies Analysis; 4. Social Organisation and Cooperation Analysis; 5. Worker Competencies Analysis. (For a comprehensive overview of CWA please refer to Jenkins et al. [8]).

A key aspect of this research and the use of this approach is that it is formative in nature describing what *could* happen if design modifications are undertaken, rather than provide normative analyses of what *should* happen. This provides the ability to identify emergent behaviors that might be brought about by particular urban designs. The reliance on normative and prescriptive approaches is often a critique of urban planning and design; that weakness is dealt with through the application of CWA [9].

3.1 Work Domain Analysis

The studies discussed in this paper involved applying the first phase, Work Domain Analysis (WDA). WDA is used to describe or model the purposive and physical constraints imposed on activity within a particular system. This involves constructing an Abstraction Hierarchy (AH) of the system in question (Fig. 1). The AH represents the system across the following five levels of abstraction:

1. Functional purpose – The overall purpose(s) or *raison d'être* of the system and the external constraints on its operation;
2. Values and priority measures – The criteria that the system uses for measuring progress towards its functional purpose;
3. Generalized functions – The general functions of the work system that are necessary for achieving the functional purposes;
4. Physical functions – The functional capabilities and limitations of the physical objects within the system that enable the generalized functions; and
5. Physical objects – the physical objects within the work system that afford the physical functions.

The output provides a constraints-based model of the system which describes the purposes, values and priorities of the system, the functions that are performed within the system and the physical resources that are used to perform the required functions. Used in a design manner, this approach enables WDA to describe what a particular system should comprise, what design features are required, and what values and priorities should be met through the design.

Significant for system design efforts is the ability to link different physical objects to required functions since this enables analyses to specify not only what a design requires but also what objects can be introduced in the design to achieve the functions.

Fig. 1. Work domain analysis abstraction hierarchy

For example, during a design process how to support the required function of ‘provide shelter’ can be explored by introducing new objects into the system. In turn, emergent behaviors from the new object can also be assessed through the links in the object. In the provide shelter example, the fact that the introducing a bus shelter obscures visibility of the roadway and traffic lights can be detected via WDA.

4 Testing the Systems Approach – Two Applications

Two applications of WDA in the urban planning and design context are presented. The first is an approach which informs new footpath design and can be used to evaluate the extent to which existing footpaths achieve their safety and sense of place requirements [10]. The second example considers a sensory urban design approach which permits access to public space by the entire community, but with a particular consideration of children with intellectual disabilities. This design approach is the vision of the *7 Senses Foundation*, and this analysis was developed with their cooperation.

In each case the WDAs were compiled from a range of data sources, including the literature on urban design; documentation review focusing on a range of national and international government policy and strategy and consultations with appropriate subject matter experts.

4.1 Safe Places for Pedestrians: Using Cognitive Work Analysis to Consider the Relationships Between the Engineering and Urban Design of Footpaths

Pedestrian footpaths provide an integral component of our urban environments and have the potential to act as safe places for people and the focus for community [10].

The WDA developed in this study provides a template for an *ideal* footpath design, based on an integration of accepted engineering and design principles, standards, policy

and practice. Figure 2 represents a summarized form of the WDA and this paper will now briefly highlight key elements from each of the levels of the AH.

Functional Purpose. Three functional purposes were established: Provide a safe public pedestrian right of way; provide safe space for utilities; and provide safe pedestrian social space (sense of place).

Fig. 2. Summarized pedestrian footpath WDA (Stevens & Salmon, 2014)

Values and Priority Measures. Ten values and priority measures are required to support the functions and the WDA highlights a range of necessary, and seemingly divergent, measures. From ‘conform with engineering standards’ through to an underlying principle of urban design ‘maximise sense of community’. Between these merge a series of important values which support and represent both engineering and urban design functional purposes – ‘maximise adherence to road rules’, ‘minimise risk from vehicles’, ‘maximise actual safety’, ‘minimise crime’, ‘maximise comfort’, ‘maximise perceived safety’, ‘maximise number of pedestrians’, and ‘maximise subjective experience’. A notable characteristic of the footpath design involves creating the subjective feeling of comfort, safety, and a positive experience. It is questionable whether subjective feelings around safety and comfort are something that are actively measured at different footpath locations however the analysis suggests that they will be key factors determining use of the footpath area.

Purpose Related Functions – Means Ends. The idea of means ends relationships are of significant value here when identifying the interfaces within the system. For example if the purpose related function of ‘provide places to meet and wait’ represents the ‘what’; and the values and priority measures (level above) of ‘maximise comfort’ and ‘maximise sense of community’ ‘maximise number of pedestrians’ are the ‘why’, then the object related processes (on the level below) of ‘provide shelter’, ‘provide surfaces for sitting’, ‘provide open space’, and ‘adjacent privately owned open space’ represent the ‘how’ in terms of how the functions are achieved.

Object Related Processes (Affordances). The object related processes have been broadly categorized here in Fig. 2, yet detailed in Table 1. When linking the objects to their affordances it is evident that the object related processes are often afforded by multiple objects. For example ‘provide shelter’ is an affordance of ‘trees’, ‘awnings’, and ‘public transit stop’. While objects which offer the affordance of a ‘landmark’ may also include ‘trees’ but may also ‘public art’ and ‘building setbacks’.

Physical Objects. At the base of the abstraction hierarchy the physical objects that comprise the ideal footpath system are detailed (Table 1). Identified from the resources were various objects that are important components of the footpath system but are not physically located within it. For example the road rules; planning regulations; budget and engineering standards are crucial parts of the system, yet physically exist elsewhere.

Testing the WDA Template. The next part of this study involved applying the template to existing footpath contexts to examine the extent to which they conformed to the ‘ideal’ safe places for pedestrian’s system design.

Two local footpath environments on the Sunshine Coast, Queensland were considered. These locations were chosen to be representative of the scope and context of the WDA [11,12]. The first case study, a footpath located on Bulcock Street, Caloundra, represents the strategic road hierarchy category of a ‘community boulevard’ and exists within the place type of an ‘urban neighbourhood’ (Fig. 3).

Fig. 3. Bulcock Street, Caloundra, Queensland Australia

The second footpath located on Aerodrome Road, Maroochydore represents ‘a multi-modal urban arterial road’ set within the place type of ‘centre of activity’ (Fig. 4). The WDA is intended to be representative of both of these footpath contexts.

Of the forty-eight physical objects identified within the WDA as contributing to the ideal footpath environment, Aerodrome Road only contained fifteen (Table 1). Consequently there is a variety of object related processes that are absent, or not being afforded by multiple objects, indicating a poor footpath environment. There are limited purpose related functions for ‘subjective urban design’ or ‘user behaviour-related functions’ both crucial to the priority measures which support the functional purpose of ‘provide safe pedestrian social space’.

Further, the Aerodrome Road environment has significant deficiencies supporting the functional purpose of ‘provide a safe public pedestrian right of way’. For example, safety related functions which are absent or inadequately supported include: provide

Fig. 4. Aerodrome Road, Maroochydore, Queensland, Australia

Table 1. Case study analysis of WDA - objects and object-related processes [10]

Case Study 1 5 Bulcock St Caloundra		Case Study 2 Aerodrome Rd, Maroochydore	
Physical Objects		Numbering Indicates associated Object-related Processes	
Footpath Zones			
Presence of an object		1. 1.4	
		2. 5.25	
		3. 5.35, 5.7	
		4. 5.15, 5.25	
		5. 5.7	
		5.10, 5.15, 5.7	
		5.46	
		7.8.23	
		8.23	
		9. 6.4	
		10. 15.26	
		11. 4.14, 2.7	
		12. 5.13	
		13. 14.21, 2.7	
		14. 5.13, 5.7	
		15. 3.41, 3.7	
		16. 5.23	
		17. 1.8	
		18. 1.8	
		19. 1.7	
		20. 3.19, 2.7	
		21. 2.3	
		22. 2.3	
		23. 3.21, 2.7	
		24. 3.21, 2.7	
		25. 3.21, 2.7	
		26. 3.21, 2.7	
		27. 12.15, 2.2	
		28. 3.24	
		29. 2.8	
		30. 3.10	
		31. 2.3	
		32. 3.0	
		33. 15.21, 2.9, 3.1	
		34. 3.21	
		35. 3.0	
		36. 25.29	
		37. 3.2	
		38. 2.6	
		39. 3.7	
		40. 3.4	
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footpath are not a priority for these roadway corridors. In both case study contexts more needs to be done to support the subjective urban design functions by way of object related processes which provide, for example, physical and psychological buffers from the travel way, user information, surfaces for sitting, shelter, access, and the generation of human activity.

The findings show instances where the existing footpaths both meet and fail to meet the design requirements specified. Through utilizing a systems approach for footpaths, this research has provided a novel design template that can inform new footpath design efforts or be used to evaluate the extent to which existing footpaths achieve their safety and sense of place requirements [10].

4.2 It's All Common Sense: Systems Analysis of a Sensory Design Approach to Inclusive Public Places

The second application focused on the concept of 'sensory urban design'. This approach is the vision of the *7 Senses Foundation* (<http://www.7senses.org.au/>) and with them it was possible to identify and understand the interdependencies between the senses and urban design.

The basis of their work and therein this STS analysis, is that people experience public spaces in vastly different ways through a diverse range of sensory inputs and outputs. This may be a pleasant or disagreeable experience depending on a person's ability to process and respond to the information. To address this, sensory urban design is now emerging as an innovative framework for the development of inclusive urban spaces.

As a concept in its infancy, there are few methodological approaches available to support the design of appropriate sensory urban spaces. The purpose of this study was to propose a methodology to support sensory urban design; in doing so, a sociotechnical systems analysis of the 'ideal' sensory public space (Fig. 5).

This again involved the construction of a WDA. The analysis incorporated key sensory design elements to build an in-depth and integrated understanding of the potential for public space to become more accessible, engaging and inclusive, ultimately providing an optimum sensory experience for users. The WDA model was also applied to two existing public spaces to assess the impact of a sensory design approach.

Functional Purpose. The functional purposes include: 'a healthy and happy community'; 'an inclusive and connected community'; and 'a healthy and active individual'. These three functional purposes of the public space system focus primarily on how users operate within the domain and their interactions with each other.

Values and Priority Measures. Twelve values and priority measures were identified. These range from 'conform to built environment standards and rules' and 'maximise actual safety'; through to values more concerned with social equity and urban design; 'enable individuality' and 'maximise engaging design elements'. These are in turn supported by a range of purpose related function which can assist in determining how the measure may be achieved.

Fig. 5. Summarized WDA 7 senses design approach

Purpose Related Functions. Here they have been summarized for efficiency but the primary categories include: ‘sensory-related functions’(e.g., provides tactile experiences, provide visual experiences, provide aural experiences); ‘safety-related functions’ (e.g., minimise motorised traffic speeds, provide protection from travel way, provide protection from climate); ‘service-related related functions’ (e.g., provides public amenity, utility maintenance, delivery of utilities and services to need); and ‘enhancement-related functions’ (e.g., maximise vibrancy, maximise diversity, maximise local character).

Object Related Processes. The object-related processes are categorized into those that relate to user comfort (e.g. provides are to wait safely and comfortably, provides shelter), way finding (e.g. enables route decision making, improves destination recognition), functional engineering (e.g. provides sanitation fixtures, transfers electricity safely) and standards and design (e.g. store information on built form and land use, store information on road rules). When linking the objects to their affordances, it is evident that the object-related processes are often afforded by multiple objects. For example ‘provides surface for objects’ is an affordance of parking space, pavement surface, fences, lawn, tables, and chairs/seats.

Physical Objects. The objects identified within the system include aspects of infrastructure design, such as tactile surface indicators, pavement surface and storm water grates, as well as associated amenities including toilets, drinking fountains, and street signage. A number of these objects can offer similar affordances, despite how dissimilar they may be. For example, while lawn and ramps are very different in form, both may provide a ‘safe surface for mobility’, in addition to providing a ‘surface for activity and play’. Similarly, one physical object may provide multiple affordances within the system. An example within the WDA shows fences linked to the following object related processes: deters vehicle from using pedestrian space; provides shade/shadow; provides a tactile surface to touch; provides a physical barrier; provides a surface for play and activity; and provides a psychological buffer between pedestrian and the roadway.

Testing the WDA Template. The *7 Senses Foundation* holds an Annual *7 Senses Street Day* and the researchers took this opportunity to test what changes may be made to a public space through the application of a sensory approach. Two case studies were considered - in Palmwoods on the Sunshine Coast and in Fairfield, Brisbane.

This paper will provide an overview of the Palmwoods case study only. Significantly, the researchers were looking for any changes in the object related processes (affordances) brought about by the insertion of new objects. Analysis of the Palmwoods Town Square found there were no changes in thirty-seven out of forty-seven of the object-related processes before or during the *7 Senses Street Day*. The case study shows an additional eleven physical objects present during than prior to the *7 Senses Street Day*, thus increasing associated levels of sensory affordance within this public space.

Object-related processes in which one level of change was recorded from 'medium' to 'high' affordance included: provides shelter; provides a landmark; provides scented flowers and foliage; provides shade and shadow; provides tactile surface to touch; provides surface for sitting; and store information on past and present experience. Occurrences of increased levels of affordances from a ranking of 'high' to 'exceeding' during the *7 Senses Street Day* include: provides illumination; and provides wind-assisted sound.

Four object-related processes were identified as absent or being represented at a 'low' level both before and during the *7 Senses Street Day* in Palmwoods. These objects include the provision of: bike storage; water display; habitat for wildlife; and the sound of water.

Overall there was an improvement of the case study site as an ideal public place (from the sensory design perspective). The model also provided data on what may be done to further improve the space and move it even closer to the desired functional purposes. As well as important template for assessing the sensory design qualities of other urban spaces.

5 Conclusion

The integration of Human Factors STS methods and the urban planning problem space provides new opportunities to better understand urban environments and how they should be designed. Constraints, complexity, and emergent behaviors are not necessarily concepts that would be associated with urban planning; however, it is clear that they have much to offer urban design and planning when they are.

This innovative cross disciplinary work has applied new thinking, ideas and techniques to urban issues. The research and application to date identifies the usefulness of a Human Factors systems approach for urban issues, allowing for an understanding of the interdependencies of intertwined functional purposes. Such an approach lets multiple disciplines and indeed stakeholders to recognize their place within the system, and the impacts and influences of urban planning and design decision-making. It makes sense that a systems approach allows for greater insights into the development of urban form. Urban planning and design practice and research needs new ways to interpret built environments and urban form as not only technical systems, but often poorly understood (and designed) socio-spatial systems.

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