CLASSIFICATION AND REVIEW OF SOFTWARE APPLICATIONS
IN THE CONTEXT OF URBAN DESIGN PROCESSES

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Abstract. We have seen increasing expectations from our cities: as we aim to enable them to become smarter, more efficient and more sustainable. Having these goals makes the urban designing process increasingly complex. Undertaking contemporary urban design and analysis requires a rounded and inclusive approach. In the discussion relating to the smart city there has been attention to infrastructure technology solutions. But ways of estimating the success of more comprehensive urban design interventions is also extremely important. In response to these needs, digital urban design simulation and analysis software packages have been developed to help urban designers model and evaluate their designs before they take shape in the real world. We analyse, and reflect on the current aids available, classifying the urban design software packages which were used in the body of knowledge. In addition, more influential urban design software packages have been reviewed to figure out in which stages of the urban design process, they have applied. This review also helpful for software developer to understand which software packages more useful and which ones need to be developed in future.

Keywords. Smart city; Urban Design Process; software application; classification.

1. Introduction

In some ways, contemporary urban design (UD) and ideas of ‘new urbanism’ take us back to 1960s ideas (Moudon, 1992). Karimi (2012) suggests that, at this time, urban designers principally relied on personal knowledge and experience; and consequently often considered limited subsets of relevant factors that might prevail. For instance, (Araabi, 2016) noted that concern might focus on visual aspects or on establishing a particular identity.

But Cities are now considered to be complex organisms with both organisation and interplay of factors seen as more important and challenging than before (Cuthbert, 2008, Al-Douri, 2013). This complexity partly explains the emergence of the concept of the Smart City. Pardo and Nam (2011) structure the smart city ideas into three conceptual dimensions: the technology dimension, the human dimension and the institutional dimension (Cocchia, 2014). Computer-mediated approaches have a role in all these three dimensions. We use computational means...
for collecting and analysing the data besides representing, engaging with and visualising the design alternatives. The overarching aim being that the quality of our decisions would be enhanced.

Broadly speaking research suggests that computational tools have not been used for urban design as extensively as they might be (Al-Douri, 2013, Fraser and Bjornsson, 2004, Billger et al., 2017). We could look at this contention from two perspectives: one view could be to say there is a need for more flexible and capable computer programs - ones that allow urban designers to employ different processes in their designs. The other aspect could be related to the nature of the urban design issue. As UD is a multidisciplinary field, it takes in a range of architecture and urban planning views. So, urban designers might use computer applications to satisfy a range of needs. As a result, the importance of software application development in this area is undeniable (Brown, 2016). And it, therefore, becomes important to understand which computer programs, could be employed and enhanced in each phase of an urban design process. To address this, we have undertaken and analysis, aimed at understanding and reporting on the position of UD software applications within the broader disciplinary body of knowledge.

The scope of applications that can fall into consideration ranges from plugins, such as those developed for ArcGIS and Rhinoceros, to aid urban design, to other bespoke software, like CyberCity3D, CityEngine, Modelur, CityPlaneer and UrbanFootprint, which provide customised platforms for this field of study.

Consequently, the primary purpose of this paper is to answer a main question: what is the extent and frequency of computational tools used in the body of UD activity and knowledge? This then leads to two further sub-questions: firstly, in which phases of the UD process, are those computational tools used?. And secondly, whether research articles report on the development of such software applications, or do they focus on the application of existing tools to certain cases?

In order to respond to these questions, first, different approaches to the different UD processes are explained and the associated, different phases are explicated. Subsequently, software packages in the reported on in research contexts and then in commercial contexts are identified.

Our systematic review of digital techniques and technologies used in the urban design process is then presented. A key initial aim of this research is to review and classify software packages in the context of the urban design, prior to development and application. The focus of this paper is to classify and examine software applications used in different phases of the urban design process.

This research has been undertaken in three stages. First, the frequency of software packages reported in the body of discipline knowledge was extracted. As a second phase, the most recently published documents and the most influential ones (in terms of citation/adoption) were reviewed and these selected reports were classified according to the appropriate phase of the urban design process (data collection, data analysis, modelling, and visualisation; see below) to which they contributed.
2. Different Phases of Urban Design Process

Carmona (2014) described the urban design as a mongrel discipline; one that justified its theories derived from different intellectual roots, such as sociology and anthropology, as well as from professional theories of architecture, landscape architecture, planning. Such descriptions reveal the breadth of the field and emphasises the need for considering a range of contributors from various disciplines involved in urban design processes.

Researchers note that different genres of UD theory result in different UD process (Araabi, 2016, Bahrainy and Bakhtiar, 2016). So, one might expect that a particular UD theory links to a specific UD process as an outcome. Consequently, it might be further expected (Al-Douri, 2017), that each design process generates the need for a specific software application to deal with it.

From the literature, a number of different UD theories can be recognised. In a very useful oversight paper, Araabi (2016) classified UD theories into three types: theories about the subject within UD, theories about the object of UD, and theories about the knowledge of UD.

Theories about the subject of UD often start by explaining a spatial problem in the built environment. Key authors in this area include Hillier and Hanson (1989), Cullen (2012), Sitte and Stewart (1945), Rowe and Koetter (1978), Trancik (1986), Larkham and Conzen (2014), Lynch (1960). Such authors have defined different concepts dealing with aspects such as:

- How to present physical forms of the city on the map,
- Morphological debates,
- Three-dimension design, and
- the composition of new buildings within in their context (Araabi, 2016).

In order to analyse the application of computer-mediated applications in urban design it is useful to identify the stages, and operations within those stages, in urban design. Understanding the differences and nature of these processes and concepts in urban design processes is important. Different researchers have described the urban design processes as existing in various stages; and there are some differences, although inherently they may at first seem to be the same. The different stages and processes will require different digital tools.

Below we articulate some important but different articulations of the process in the context of urban design:

- Shirvani (1985) categorized the conceptual foundations of design methods by identifying six types: internalized, synoptic, incremental, fragmental, pluralistic and radical. He considered internalized and synoptic approaches to be the most common methods used by both designers and planners. The synoptic method is described as ‘comprehensive’ and is described as occurring in seven steps:
  1. Data collection, the survey of existing conditions- natural, built and socioeconomic
  2. Data analysis, identification of all opportunities and limitations
3. Formulation of goals and objectives
4. Generation of alternative concepts
5. Elaboration of each concept into workable solutions
6. Evaluation of alternative solutions
7. Translation of solutions into policies, plans, guidelines and programs

(Shirvani, 1985)

- In the RIBA practice and management handbook, the design process is divided into four phases as follows:
  1. Assimilation: the accumulation of general information and information especially related to the problem.
  2. General Study: the investigation of the nature of the problem, the investigation of possible solutions.
  3. Development: the development of one or more solution.
  4. Communication: the communication of the chosen solution/s to the client.

(Cuesta et al., 2012)

Other scholars have undertaken research, aimed at classifying computer-aided tools in the context of urban design; for instance, see (Brown, 2016).

- Brown emphasised the need for having a Design Information System applied to urban design. He refers back to the seminal work of Eastman (1979) and articulated five issues related to the development of a Design Information System:
  1. Spatial modelling
  2. Integration of attributes
  3. Database management
  4. Design development
  5. Design coordination

(Brown, 2016)

Charlton et al. (2008) classified computer programs used in the UD process to six classes: 3D modelling, pedestrian modelling, noise mapping, thermal comfort software, wind analysis software, platform (VR engine). The focus of their survey was using software and computational tools for the design of a specific urban space; the design of a square.

- Al-Douri (2017) has undertaken research relating to the effectiveness of computational and modelling tools in urban design development processes. He characterised the different aspects in the urban design development process as having four functions:
  1. Navigation-Visualisation,
  2. Communication-Collaboration
  3. Analytical functions
  4. Simulation & Decision-Support function

(Al-Douri, 2017).

Examining the different design process analyses, it is clear that the different stages in the urban design process identified by each of the researchers have overlaps. In order to undertake our classification, we have looked for a broad
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categorisation and have therefore used four unifying terms to describe the stages for the purpose of this paper:

1. Data Collection
2. Data Analysis
3. Modelling
4. Visualisation

In Table 1 we show how each term in our classification relates to the classifications by others. However, each is not a rigid classification, and each stage may have overlap with other stages. By having this simplified over-arching classification, we could then codify the position of software applications in the UD process. Subsequently, we could analyse the frequency of software packages used in different stages of the design process, in our empirical studies, in relation to this structure (see Table 1).

Clearly, there is not a perfect match between the terms used by other researchers and our terms. For instance, our term “visualisation”, is intended in its broadest sense to incorporate the representation of analysis outcomes. Table 1 illustrates how our classification maps onto the classifications of four others.

Table 1. Different attitudes towards Urban Design Process classifications.

<table>
<thead>
<tr>
<th>In this paper</th>
<th>All Dorti</th>
<th>Brown</th>
<th>The SRA handbook</th>
<th>The systematic design method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Collection</td>
<td>Navigation, Visualisation</td>
<td>Database management</td>
<td>Assimilation</td>
<td>Data collection, the survey of existing conditions - natural, built and socioeconomic</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>Analytical functions</td>
<td>Integration of attributes</td>
<td>General Study</td>
<td>Data analysis, identification of all opportunities and limitations, formulation of goals and objectives</td>
</tr>
<tr>
<td>Modelling</td>
<td>Simulation &amp; Decision-Support function</td>
<td>Spatial modelling</td>
<td>Development</td>
<td>Generation of alternative concepts, formulation of each concept into workable solutions, evaluation of alternative solutions</td>
</tr>
<tr>
<td>Visualisation</td>
<td>Communication, Collaboration</td>
<td>Design coordination</td>
<td>Communication</td>
<td>Translation of solutions into policies, plans, guidelines and programs</td>
</tr>
</tbody>
</table>

3. Urban Design Software Applications

In computer science, one type of specialized software is computer-aided design (CAD) applications, which are conventionally understood to be drawing, geometric modelling and rendered images of building and products. Hussain (2017) categorises urban design software applications as CAD applications, though this somewhat misses the point that as the discipline had become more sophisticated in the use of digital technologies, and the adoption of a wider base of computer-mediated techniques has become prevalent.

As there is no specific source that identifies urban design software applications, in this paper, we provide the lists of software applications which mentioned in the literature that relate to urban design.

Undertaking a review and analysis of academic and research references, we recognised seven applications that were evident: Esri CityEngine, CityPlanner,
Modelur, Space Syntax (DepthmapX & QGIS), Urban Modelling Interface (UMI), ArcGIS, and UrbanFootprint (see Figure 1).

The Capterra Software Catalogue (Capterra, 2018) is a database that we used that for identifying the UD software packages, from the commercial view. However, there is no UD related classification offered by Capterra. The four related key classifications presented by Capterra Software database were 3D Architecture Software, Architectural CAD Software, Architecture Software, and Landscape Software. Those software applications which can use only in the context of architecture or landscape architecture were eliminated. So, the results reduced to eight software applications (see Figure 1).

The processes described above thus produced Figure 2, which shows our analysis of applications found in practice focussed sources. Figure 1 shows the analysis of applications referred to in Urban Design Research sources. The size of the circle indicates the occurrence and application of the particular technique for each particular purpose.

Figure 1. Urban Design software applications from the academic resources (Left), Urban Design software applications from the Capterra catalogue (Right).

4. Method
Empirical studies were undertaken to evaluate which software applications were most frequently adopted, and in which phases of the UD process. This was done by reference to reports, articles and papers readily available in the current body of knowledge (see stage 1 details below).

This research has been undertaken in three stages. First, the frequency of software packages in the body of UD knowledge has been extracted. Second, recently published papers and the most influential ones has been focussed on. Then, selected papers arising from the previous two stages, have been classified according to the urban design process to which they contributed. Finally, selected papers have been classified by their focus whether they have written:

- to report the development of software/code or
- to describe the application of a specific software package to a particular case/problem.

Stage 1: a list of software packages identified above in the section three of this paper, were searched for through databases. This took in eight databases including CumInCAD, ACM Digital Library, Scopus, Springer Links, Wiley Online Library, Web of Science, Science Direct, and ProQuest Central. In this research, only
articles published in English from 2008 to 2018 were considered. The articles not relevant to the urban design field were eliminated.

Stage 2 and 3: articles published in the last two years, 2017 and 2018, were assigned the designation ‘recently published’ and two papers with the highest citations were chosen as ‘influential’ ones. The citation of articles assessed in Google Scholar took place in November 2018. The software applications mentioned in articles, were classified by their contribution in the phases of the UD process. The classification of the UD phases which are described in section three of this paper were used for classifying the selected articles. The other criteria which were considered for sorting the articles involved ascertaining whether they focussed on the development of the software application or whether they present the application of the software.

5. Results

Figure 2 shows software packages which have been extracted from the commercial database. It reveals an expected dominance use for the purpose of modelling and visualisation, while the main focus of those which are derived from academic/research references (see Figure 1) are primarily focussed on the data analysis and modelling phases. Moreover, there are just two bespoke software packages that cover nearly all phases of the urban design process, ArcGIS and UrbanFootprint.

The result shows four software applications - Space Syntax (DepthmapX & QGIS), ArcGIS, SketchUp, and CityEngine - are the most used ones in the urban design process (see Figure 3). Space Syntax (DepthmapX & QGIS) and ArcGIS dominate so substantially compared to the other recognised software applications that a different y-axis scale is used in Figure 3. With the frequency less than 200, SketchUp and CityEngine are the next stages.

Figure 4 shows the distribution of academic references from 2008 to 2018, that have Space Syntax (DepthmapX & QGIS) and ArcGIS as the focal software. This shows that researchers have employed these software packages increasingly. What is interesting to note is the similar phenomenon on both graphs. For both Space Syntax (DepthmapX & QGIS) and ArcGIS there is a significant increase in citation and application from 2013 to 2018, compared to the frequency of citation from 2007 to 2013.

This is partly due to a general increase in the number of papers and citations but even given this, it is notable that there has been significantly increased interest and attention for both of these cases.

Table 2 adds more specific detail to the overall analysis summarised in Figures 3 and 4. Recent and most cited papers are analysed to evaluate their focus and attention. The final two columns indicate whether the attention was on using the software as a tool, or whether it was focussed on the enhancement of the software itself. In the case of the use as a tool to examine a particular problem the location of the application case is shown in the table.
Figure 2. The frequency of software applications in the body of Urban Design Knowledge from 2008-2018.

Figure 3. The frequency of ArcGIS and Space Syntax (DepthmapX & QGIS) in the body of Urban Design knowledge in each years between years 2008 to 2018.

Some comments can be made as a result of the study summarised in Table 2:

ARCGIS - This has most highly cited papers in recent years (2016-18). The primary use of the software has been in the application of the software via exploitation as a data analysis tool. However there is an interesting case (Omer and Kaplan, 2017) of a visualisation of the non-visual.

SPACE SYNTAX (DepthmapX & QGIS) - The main focus in the four papers here has been development of the software/code itself. And the most frequently cited occur in 2014 and 2015.

SKETCHUP - The references here focus entirely on using the software as a key part of an application process. The primary use if for data analysis and modelling.

CITY ENGINE - In the case of CityEngine the attention in published works is on modelling and visualisation applied to a particular problem. Easily the most heavily cited paper (Xu and Coors) was written in 2012.

6. Discussion

The results of this paper support the assertion about the lack of a comprehensive computer program for the Urban Design field; one that covers all phases of the urban design process (Gil, Beirão, Montenegro, & Duarte, 2010). However,
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ArcGIS and UrbanFootprint appear to offer a comprehensive suite of possibilities. We should note that the introduction of the facility for accessing real-time data also adds to the broader scope and potential in the case of these two applications.

Table 2. Review of influential and recently published articles.

<table>
<thead>
<tr>
<th>Title of papers</th>
<th>Authors</th>
<th>Citation</th>
<th>Year</th>
<th>Data collection</th>
<th>Data analysis</th>
<th>Modelling</th>
<th>Visualization</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Form Syntax&quot; as a contribution to geography: A morphological tool for urbanity-making in urban design</td>
<td>Yu Yu, A.Yeh, Yi-Chung, Nan Niu and J.Lu</td>
<td>15 2017</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Netherlands</td>
<td>B</td>
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<tr>
<td>Filling the space between towns and place: Adopting the 'Movement &amp; Place' framework to Melbourne's main network</td>
<td>M.J. Oliver, G.Currie, C.N. Gagey, J. Shults</td>
<td>1 2018</td>
<td>○</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>Australia</td>
<td>○</td>
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<tr>
<td>Using space syntax and agent-based approaches for modelling pedestrian volume at the urban scale</td>
<td>D.Omer, N.Kaplan</td>
<td>3 2017</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>Israel</td>
<td>○</td>
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<tr>
<td>Panasonic modelling with GIS</td>
<td>P. Jensen, B. Sørensen, A. Molayey, E. Tan, H.Ni</td>
<td>1 2018</td>
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<tr>
<td>Spatial-Urbanisation: Mapping Anthropo-Spatial graph networks and evolutionary design in Grasshopper: Mapping Anthropo-Spatial graph networks and evolutionary design in Grasshopper</td>
<td>K. Kang, Y. Yvanoff</td>
<td>1 2015</td>
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<tr>
<td>The space syntax toolkit: Integrating DephaseX and exploratory spatial analysis workflows in QGIS</td>
<td>F. Gentile, A. Varoudis, K. Karamitrou, A. Pande</td>
<td>2 2015</td>
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<tr>
<td>Using space syntax to model pedestrian movement in urban transportation planning</td>
<td>Y. Lerman, Y. Rudi, J. Omer</td>
<td>3 2014</td>
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<td>Israel</td>
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<tr>
<td>Evaluating procedural modelling, for 3D models of informal settlements in urban design activities</td>
<td>V. Ronen, C. Y. Ben, S. Coner, C. Gehale</td>
<td>7 2015</td>
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<td>○</td>
<td>○</td>
<td>South Africa</td>
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<tr>
<td>Research and design for thermal comfort in Dutch urban squares</td>
<td>Y. Lendeboeck</td>
<td>27 2012</td>
<td>○</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>Netherlands</td>
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</tr>
<tr>
<td>The study of the effects of building arrangement on microclimates and energy demand of CHD in Toronto, China</td>
<td>Y. Dong, H. Mi, W. Hong, Z. Zhong</td>
<td>4 2016</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>China</td>
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<tr>
<td>The nutritional analysis of outdoor social and thermal environment in a residential area in Lisbon, China</td>
<td>L. Zhang, Z. Yu, J. Liu, L. Zhang</td>
<td>1 2018</td>
<td>○</td>
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<td>South Africa</td>
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<tr>
<td>Using Panosonic Modelling in Form-based Code Design for High-rise CHs</td>
<td>M. Schröder, Y. Zheng, S. Sylwan</td>
<td>2 2017</td>
<td>○</td>
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<td>○</td>
<td>Hong Kong</td>
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<tr>
<td>Combining system dynamics model, GIS and 3D visualization to sustainability assessment of urban residential development</td>
<td>X. Xu, Y. Cao</td>
<td>187 2012</td>
<td>○</td>
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<td>Germany</td>
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<tr>
<td>City 3D: A postreflection method and tool for three-dimensional modelling of urban environments</td>
<td>O. Krüger, S. Bielagl, G. Leible</td>
<td>1 2017</td>
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The analysis in the sections above shows that in the research domain certain software is being developed in response to perceived need and that development is being reported on. In the commercial/practice field the focus is, as we would expect, on the application of the tools rather than the development of them.

As we aim to improve city design and associated processes with the aim of achieving the smart (intelligent?) city, one of the effective ways to support that is to develop our current Urban Design process by having more productive, capable and reliable computational tools. This paper analyses, and makes some consequent reflections on the development and exploitation of such tools over the past ten years or so.
References

EASTMAN, C. M.: 1979, The computer as a design medium, Department of Architecture, Carnegie-Mellon University.