

# Assessing Computational Tools for Urban Design

## Towards a “city information model”

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**Abstract.** *This paper presents an assessment of a selection software tools for urban design confronting their capabilities with the goals of the CityInduction research project. The goal of this paper is the assessment of existing platforms for computer aided urban design to select one as the basis for implementing the urban design model proposed in the CityInduction project. This model includes three sub-models that support the formulation of design programs from contextual information, the exploration of designs solutions through a grammar-based generative approach, and the validation of designs against the program through the use of evaluation tools. To each of these sub-models corresponds a module in the envisioned platform and so, existing platforms are assessed in terms of their ability to support the implementation of each module. The current goal is a proof-of-concept implementation, but the final goal is the development of a complete platform for supporting urban design.*

**Keywords.** *Software review; sustainable urban design; GIS; CAAD; BIM.*

## Introduction

Computer Aided Architectural Design (CAAD) software is well established within architectural practice and teaching, with a wide range of tools for the design, drafting and modelling of buildings. However, when it comes to dealing with urban design those tools do not seem to adequately address the complexity of the urban environment, as they lack the ability to manage the contextual and site information needed to support and describe an urban plan.

To some extent, Geographic Information Systems (GIS) have been used to support this evidence-based design approach, but they lack the usability and design features necessary for its wider adoption

by designers within a creative design process (Maquire 2003).

In recent years, Building Information Models (BIM) have gained presence in the field of CAAD by offering the combination of databases with building information with detailed design features based on a sets of building element patterns. Is there a similar software paradigm for urban design? This paper explores the state of the art in what is becoming known as a “City Information Model” (CIM) (Khemlani, 2005; Hisham, 2010).

## Context

In this paper we assess a selection of the software tools publicly available that are specific for urban

design. The aims are, first, to identify a preferred platform for the development of prototypes for the CityInduction urban planning tool, and then to determine the structure of a platform built from scratch for such a tool aimed at the integration of the urban design process, represented by three modules, i.e. formulation (1), generation (2) and evaluation (3), in a CIM database system. The purpose of the a tool is: (1) to read data from the site context in a GIS platform to formulate adequate program descriptions; (2) to generate alternative design solutions that match the given program, and (3) to evaluate evolving design solutions against the program to obtain satisfactory results and to determine the intrinsic value of each solution regarding aspects like sustainability.

The assessment is done from the perspective of a research group requiring a platform to prototype a specific urban design process discussing how it supports its various phases. We focus on the technical capabilities and the core principles behind each tool, and the possibilities to expand the tool's functionality to incorporate new features and concepts.

### Approach

Firstly, we introduce the selected tools, give a short description and then describe the assessment process. Next, we highlight how each tool performs from the perspective of the three modules of the CityInduction project. Finally, we discuss the key features that are missing, and present the final decision on the preferred platform.

### Selection of CIM tools

The tools most frequently used by architects and planners in urban design projects fall in one of the two groups: CAAD, e.g. AutoCAD, Microstation and Vectorworks, or GIS, e.g. ArcGIS, MapInfo and Manifold. What we are looking for is a new breed of software that departs from one of the paradigms and merges important features from the other to create a platform that can be called a CIM. Those tools must address some of the features that are of interest for

the sustainable urban design framework proposed by CityInduction, namely they:

1. Incorporate an urban ontology;
2. Respond to the planning regulations and strategies defined for the site;
3. Consider the context, holding information of both site and population;
4. Support the formulation of programs for urban intervention;
5. Provide a selection urban design patterns;
6. Include a generative design model;
7. Perform the analysis of sustainability indicators;
8. Allow the interaction between data and design;
9. Provide an interactive visualisation of data;
10. Perform the evaluation and rating of different designs.

Based on the research of academic literature in the CAAD and GIS fields, on-line resources for urban design and referrals from practitioners, we have selected the following software tools for review:

- CityCAD version 1, by Holistic City [1]
- CityEngine 2009, by Procedural [2]
- CityZoom, by SIMMLAB [3]
- AutoCAD Civil 3D 2009, by Autodesk [4]

Also worth mentioning is a new tool called Modélur [5] that at the time of the research was still in pre-beta stage and had quite limited functionality but promised to address some of the CIM requirements, in particular with respect to testing building regulations.

### Summary of the selected tools

#### CityCAD

CityCAD is a Microsoft Windows tool launched in June 2008, developed in the UK by a company called Holistic City. Departing from a design oriented CAD paradigm, it focuses on the development of an interactive interface, incorporates an urban design ontology, with attributes assigned to the design entities, and reports on a variety of design analysis data (Holistic City Software 2010; de Boer 2009). Version

2.0 will be launched soon after this research is completed promising new features at all levels.

### **CityEngine**

CityEngine is a Microsoft Windows, Mac OS X and Linux tool stemming from research originally conducted at the ETH Zurich by Pascal Mueller (Muller 2006; Watson et al. 2008; Weber et al. 2009) and subsequently launched by Procedural in 2008 in Switzerland. Its primary target audience are the movies and video games industries, focusing on the visualization aspects of richly realistic cityscapes, but its generative features have attracted the interest of urban designers and features have been added to increase its use in this field.

### **CityZOOM**

CityZoom is a Microsoft Windows tool developed over 15 years at the SIMMLAB of the Universidade Federal de Rio Grande do Sul (UFRGS) in Brazil by Benamy Turkienicz and Pablo Grazziotin (Turkienicz et al., 2001; Grazziotin et al., 2007; Turkienicz et al., 2008) as a product of academic research. It is not available as a commercial package but has been presented at various international conferences and workshops. It is presented as a design support platform that complements the use of CAD and GIS systems for some urban design specific tasks, in particular the simulation of urban design regulations.

### **AutoCAD Civil 3D**

AutoCAD Civil 3D is a Microsoft Windows tool based on the popular CAD package from Autodesk, but extending it primarily with features specific to road and urban site design and with several GIS features, attempting to merge both types of software package. This tool is freely available for academic use from the Autodesk website.

## **Assessment Methodology**

The CityInduction team knowledge of the tools is based on the experience acquired in formal training

sessions, i.e. CityEngine workshop in 2009, CityZoom course in 2009, AutoCAD Civil 3D course in 2008, and in completing on-line tutorials for CityCAD and CityEngine.

The selected software tools are assessed according to the features they offer to support each of the three modules of the CityInduction urban design project: formulation, generation and evaluation. We also assess the tool's underlying urban design ontology in terms of the structure and dynamics of their object model. Within this framework the tools should be able to support an iterative workflow towards a final design solution. Finally, because none of the tools offers the complete set of features, an important characteristic that we assess is the extent to which the tool allows for an easy development of extensions, in order to evolve into a system that provides all the desired features.

Table 1 maps the various features of the urban design framework used as tool selection criteria for each of the selected software platforms, differentiating the various levels of implementation of the different features.

## **Assessment of the tools**

### **Object Model**

All the selected tools are based on an object model that can be seen to constitute the core elements of an urban ontology. The objects in common between all the tools are 'street', 'block' and 'plot', and with the exception of AutoCAD Civil 3D, they also include 'building' and 'pavement'. But there are significant differences in the implementation of the object model and the extent to which it gets further detailed.

CityCAD has an object model that starting from the street creates pavements, blocks, plots and buildings. It includes a site boundary element as well. The street is the main generator, from which blocks are created maintaining their topological integrity even after the streets are edited. Blocks can be subdivided

*Table 1  
Features required for a CIM  
offered by each of the selected  
urban design tools, indicating  
if the feature is A – built-in;  
B – built-in and customizable;  
C – partially implemented;  
D – not implemented but  
extendable.*

<b>Feature</b>	<b>CityCAD</b>	<b>CityEngine</b>	<b>CityZoom</b>	<b>AutoCAD Civil 3D</b>
Incorporate an urban ontology	A	A	A	C
Respond to the planning regulations and strategies defined for the site	A	B	A	D
Consider the context, holding information of both site and population	C	B	D	D
Provide a selection urban design patterns	B	D	-	B
Support the formulation of programs for urban intervention	C	-	B	D
Include a generative design model	C	B	C	D
Perform analysis of sustainability indicators	A	-	C	D
Allow the interaction between data and design	C	C	C	C
Provide an interactive visualisation of data	B	-	B	B
Perform an evaluation and rating of different designs	-	-	-	-

into smaller plots, which in turn can be converted to buildings. Each object has a series of sub-types, which to some extent can be customized, in particular the street profiles using a specific editor.

The object model in CityEngine is similar to CityCAD's. However the dynamic interaction between elements does not exist and as one progresses through the design process the first element, the street, cannot be edited without having to start all over again. Still, information can be passed between entities at certain stages of the process thanks to topological relations.

In CityZoom, the object model includes the street and it is one of the input layers. Nevertheless, it does not seem to play any further role in the process and it cannot be edited from within the tool at any stage. This makes the street layout a fixed constraint rather than an urban design element. As a consequence, the block entity becomes more important and constitutes the starting point when editing a layout. In addition, the street pavement is a property

of each block instead of part of the street profile. The building element can be generated from the building regulations or imported, but in the latter case it is not a parametric entity. There are no further levels of detail available below these base objects.

Civil 3D has an object model that does not include the building. However, it includes the site and the terrain, thereby demonstrating a focus on more structural and larger scale design features. Still it includes a detailed street section typology tool with all the usual components. Also, other objects can be created using the GIS Map topology features. The major drawback is that, despite the attempt at integrating CAD and GIS features, the object models of the different parts of the software, i.e. AutoCAD, Civil and Map, is neither shared nor compatible. Still, it is an extensive platform containing scattered tools partially addressing functionalities that could provide a more complete and integrated object model, namely the production of custom entities using the ObjectARX programming environment, data management

and data integration with the object model through the use of Extended Entity Data (XData), XRecords or Extension Dictionaries, not to mention the various available programming interfaces.

### **Formulation**

None of the assessed tools includes a module that completely supports the development of programs for urban intervention, given site and population data or other contextual information. Despite the strict specialization of these tools, some provide for contextual data available and include mechanisms that would enable their extension with the development of a program formulation module.

CityCad seems to enclose further visual and interactive planning procedures, yet it does not seem to have sufficient extensibility. It is the only of the assessed tools that takes into account population data, although in an indirect way by considering the number of dwellings, which permits the development of different kinds of analyses to support the development of urban programs. Limited formulation rules can also be implemented by editing street and building configurations, though it entails a diffuse formulation process. Unfortunately, the site information and urban typologies parameters can only be entered manually via the user interface and it would benefit from a direct support for GIS formats.

CityZoom chart tabs permit the development of more detailed rules; nonetheless, it lacks relevant contextual data to support the definition and application of such rules, such as certain site features and population data.

CityEngine provides little basis for developing urban formulation rules, which is not surprising given that its original aim is to quickly build realistic cityscapes for the entertainment industry, without any planning concerns. However, in the early stages of the process, it allows one to load raster images that can carry site attribute information or represent urban development constraints. One can envisage this feature being used with raster images produced by an external GIS package containing urban program

data to inform the generation process; nevertheless programming would be performed outside the tool with no dynamic relation to the generated model.

AutoCAD Civil 3D, on the other hand, seems to fare better in this respect due to its GIS capabilities, which can be used for extracting relevant data for feeding the formulation process. However, even in this case such a module would have to be built from scratch.

### **Generation**

In CityEngine the only pre-set types relate to street grids, and all other typologies for street sections, plots or buildings are defined by custom rule sets. Because the software is clearly oriented towards obtaining realistic and convincing cityscapes as required by the entertainment industry, its main functionalities concern the development of building facades. The street profile rules are limited in the sense that the street model contains only 2 different street hierarchies in the version we assessed and 3 in later developments, which limits the design of the street network considerably. The algorithms for generating the street network are not accessible however some rule parameters can be specified. It is the only software with a built in grammar-like generative model and although customizable to a certain extent, it is incomplete and not fully accessible.

CityCAD has a very powerful parametric structure and a user-friendly interface. Of the assessed software, it is the one that provides a more clear understanding of what the urban design process is about, using the parametric model to dynamically record and manage data from what is being designed. But it is fundamentally a parametric design tool that lacks more powerful generative capabilities and has no programming interface that allows its extension.

The generative features in CityZoom concern the simulation building regulations to allow a quick visualization of their impact on the design of a particular block or area. For this purpose, it includes an interface for editing the regulations parameters.

However, it does not contain any tools for designing the street network, thereby restricting utility of the software to the study of the relations between plot and building parameters within a grid imported through a dxf file.

AutoCAD Civil 3D is the tool that provides more utilities, but with little integration despite sharing the same platform. However, the utilities cover with considerable detail most of the features needed to define a CIM with generative capabilities. These features are: the Map platform, which is a reasonably up to date GIS platform; the CAD platform, which is a well-known and extremely powerful CAD tool; and a platform for designing roads that is specific of Civil 3D. Other features like scripting interfaces, the parametric block design interface, the block attribute manipulation, the object class creation tools, and the external entity data manipulation, among others, provide for the widest set of capabilities among the assessed software, despite its integration limitations. The most interesting aspect is that the platform provides the most important mechanisms needed for the CityInduction goals, which are the possibility of storing information associated with drawing entities and the programming interfaces needed for this purpose. In addition, the fact that some shape grammar interpreters have already been implemented in AutoCAD also made it suitable for implementing the generation module. In fact, the parallel assessment of the few available shape grammar interpreters showed that, despite their merits, they would require one to build the urban ontology data structure to allow for meaningful rule applications, which seemed as cumbersome as building a new rule engine into AutoCAD.

### **Evaluation**

None of the tools has true evaluation features, which would include the setting of evaluation criteria, weights and benchmark values leading to the rating of different design options by synthesizing the analytical results quantitatively and graphically, as is the case with the GIS tool INDEX by Criterion Planners

(Allen, 2008). However, they offer analysis and visualization features that are essential methods to support such an evaluation process.

CityCAD is the most complete tool in its set of analyses, covering a series of themes including the environment, mobility, economy and liveability of the master plan, and offers a wide range of outputs including a summary report. The set of analyses is predefined and cannot be extended beyond the customization of certain parameters and not for custom calculations. Further analysis needs to be made by exporting the model's data to other software. A limitation of its analysis is that it only takes into account the master plan itself and the site's context is eventually included only for visualisation purposes as a larger plan image or a static 3D model.

CityEngine does not offer any analysis features apart from a very realistic and interactive visual representation of the resulting design. However, the model's geometry and attributes can be exported for analysis in other platforms.

CityZoom offers both visual and quantitative analysis of the designs. The first by generating 3D views for visual impact and shadow studies, the second by transferring the resulting design to its Mosaic module, which has certain GIS thematic mapping features. The set of attributes available for analysis is restricted to morphologic ones relating to size, area or volume and the output is raster-based always showing the distribution of densities in a regular grid of variable size. For more comprehensive spatial analysis, including other attributes of the plan, the use of a full GIS package is recommended. There are other modules, such as Aximagic for space syntax axial analysis, or for solar and wind analyses still under development, all using the 3D model created in the core platform but with no interaction among them.

AutoCAD Civil 3D does not offer the typical analyses of urban form for the evaluation of an urban design, as identified in Gil and Duarte (2010). It includes a limited set of analyses specific to road design and terrain modulation and thanks to its Map components it also includes all the basic features of a GIS

package, e.g. attribute and spatial queries, thematic maps, buffers, topology analysis and network analysis. These can be used to produce a large variety of spatial analyses of the design options. However these are not offered out of the box and will require a good knowledge of GIS and eventually the development of specific plug-ins.

### **Extensibility of the platform**

The selected tools have varying degrees of extensibility, from the customization of parameters to opening themselves to the development of complete new features.

CityCAD and CityZoom are based on parametric objects, whose libraries can be added to, and are editable at the level of urban regulation benchmark values and analysis parameters. This is achieved using the dialog boxes provided in the standard user interface. But they are not extensible by non-programmers and would require direct collaboration with the developers to add new features. One way to have some control over those tools programmatically is by manipulating their native files, which in both cases are in a human readable text file format. This also opens up the possibility of integrating the tools in more complex workflows, but it is a “hack” and is not supported by the developers.

CityEngine offers a couple of different scripting environments. One is the Java based shape grammar rule scripting environment that operates at the level of plots and buildings. The other is a Python based Input/Output scripting environment to facilitate the development of new importers and exporters and expand the possibilities of integrating CityEngine in new workflows involving other software.

AutoCAD Civil 3D has the most open architecture of all the reviewed tools. It has a macro recording feature, two scripting environments, i.e. Visual LISP and VBA, and a public API that give access to the core object model and methods of the tool using the Microsoft .net platform. Furthermore, the Map features provide links to a variety of GIS spatial databases, which offer in them the means to manage, query

and manipulate all the geometric and attribute data stored in them. These options give limitless possibilities for customisation and expansion of the tool suitable to different levels of expertise.

### **Discussion**

CityCAD and to some extent CityZoom are intended for use in the urban design process by planners and designers. CityCAD is clearly the tool that more comprehensively tries to address all areas of the design process. It offers a simple interface to manipulate the design, to configure various parameters of the plan and offers a wide range of analytic features. However it lacks a parametric or rule based design system and the setting up of programme requirements is still limited. CityZoom on the other hand supports the decision making process and as such the role of regulations and parametric constraints is more present, offering a rule based system for generating different building massing design solutions.

CityEngine and Autodesk Civil 3D were not originally thought for the urban design process. The first is a city generation tool for visualisation in games and movies and the second is an engineering tool for road design. However each has particular features that raised interest within the urban design community. CityEngine has a strong generative engine based on an urban parametric model and a type of shape grammar that is capable of producing realistic looking cities very fast. However, the urban model needs expanding to incorporate a wider range of urban patterns and it still needs analysis and evaluation capabilities to produce sustainable designs, according to a set of programmatic criteria. Autodesk Civil 3D has the advantage of merging a CAD and a GIS system, offering the best of both worlds, and is the only tool that incorporates the topography as an important element of its ontology. The Civil 3D platform was clearly developed for road design, with a very advanced street model and analysis features specific to those tasks. Although very powerful and complete in some of their specific functionalities, the

CAD, Civil and GIS systems are not very integrated and its ontology is still short of being an urban one.

Autodesk Civil 3D is by far the tool with more potential for expansion and prototyping. For this reason it was finally the platform chosen to implement the various modules of the CityInduction project.

## Conclusion

We conclude that at present there is not a single comprehensive platform that addresses all the features proposed for the CityInduction urban design process. As such, some platforms are more suited for specific parts of the urban design process than others. The degree to which each of the reviewed platforms is open and provides potential for expansion is, therefore, important and has determined the current choice of platform. AutoCAD Civil 3D seems to fare better overall when taken into account the potential for implementing the different modules of CityInduction. In addition, it provides better expandability capabilities and so it was the platform selected for the current, proof-of-concept implementation. The ultimate goal, however, will be achieved with the evolution of an urban design platform into a CIM.

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