City Information Modelling (CIM) and Urban Design

Morphological Structure, Design Elements and Programming Classes in CIM

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In architecture, there was an evolution from Computer-Aided Design (CAD) to Building Information Modelling (BIM), but in urban planning and design, where the Geographic Information Systems (GIS) are often used, there is no such analogy. This paper reviews research in typo-morphology, a branch of urban morphology, procedural modelling of buildings and cities and 3D city modelling and visualizations. It presents a generic morphological structure of urban elements and discusses them as programming classes in City Information Modelling (CIM) and the application of CIM in urban design practice. Urban design can be understood as an art of juxtaposing and arranging urban design elements such as streets, sidewalks, buildings, building façades, landscaping, etc. Designing implies experimentation and play on design elements within design worlds. CIM should integrate procedural modelling, urban morphological research with toolboxes of design elements and rules of combinations. CIM should serve as digital design worlds where urban designers can play with design elements, model and analyse urban scenarios with generative procedures, rules and typological processes.

Keywords: City Information Modelling (CIM), urban morphology, morphological structure, urban design, design element, programming classes

INTRODUCTION

With the emergence of Computer-Aided Design (CAD) in the 1970s and Building Information Modelling (BIM) software in the 1990s, architects digitized their design studio world with drawing board and toolbox of architectural elements. The lines and arcs in CAD became walls, columns, slabs, etc. in BIM. BIM furthermore produces typical architectural drawings (site plans, building storey plans, building elevations, sections and details in two dimensions, and axonometric projections and perspectives in three dimensions). Influential handbooks and reference books about architectural elements are used internationally for more than half a century years (Neufert, 2012 [1936]) and they served as background to develop ArchiCAD in the 1990s. Architects have reached a consensus about standardized symbolic representations and architectural elements already in the 1930s.
It is well established at the academy and practice. In contrast to architectural professionals, urban planners and designers have different interpretations of cities. Their representation of cities vary from stories and narratives, painted cityscapes to complex mathematical models and computer simulations (Stojanovski, 2013). For architects and urban designers, a plan is a drawing. For an urban planner, plan is often a written document (Walters, 2007, p. 19). For an urban analyst it is a dynamic database of urban variables. Geographic Information Systems (GIS) allows for analysing and visualizing data at these scales that is crucial for urban planning. GIS and conventional zoning are common in urban planning practice. Urban planners and designers usually arrange land uses in master plans at a scale of plots, city blocks or neighbourhoods in two dimensions.

Urban design can be understood as art of juxtaposing and arranging urban design elements such as streets, sidewalks, buildings, building façades, landscaping, etc. in urban space (Taylor, 1999; Marshall, 2016). Urban designers have advocated replacing conventional zoning regulations with more detailed urban design guidelines (Duany & Talen, 2002; Talen, 2002; 2009; 2013; Walters, 2007). According to the Form Based Code Institute (FCBI), conventional zoning regulates urban development by setting land uses or employment and residential densities, Floor Space Indexes (FSI), Open Space Indexes (OSI), and parking requirements. FSI is usually referred to Floor Area Ratio (FAR). FSI is the product of the total area on every floor divided by the area of the plot. OSI is the product of the open area of the plot (the area of the plot minus the area of the ground floor) divided by the area of the plot (measured in percentage). In addition urban design guidelines and Form-Based Codes (FCBs) include conventional zoning requirements plus street and building types, frequency of openings and building façade regulations, street to building height ratios t build-to lines, number of floors and specifications about percentage of open street frontage (FBGI, www.formbasedcodes.org). GIS do not focus specifically on symbolic representation of urban elements such as streets, buildings and plots or their interaction (building to surrounding open space on a plot, street to building, building with building, neighbourhood with neighbourhood, etc.) that are integral for FBCs. Instead of design toolbox, it has drawing tools for generic elements (points, lines and polygons) and editor to insert or modify the attribute of these elements.

Urban planning and design professionals needs digital tools that like GIS integrate data for analyses, but they also have design capabilities. There is a need to expand GIS with a BIM analogy in urban planning and design referred to as City Information Modelling (CIM). CIM has to link experiential qualities of cities in three dimensions with the planning and development process and in the regulatory environment, but also with design practice. It needs to integrate knowledge about theories and histories of urban form; methods for observing and measuring; as well understandings of natural systems in urban environments, as well as transportation that play such a powerful role in shaping cities (Southworth, 2016). A drawing of the city cannot represent this complexity of the city. The city is instead experienced kinaesthetically as sequences of urban spaces (Cullen, 1961; Taylor, 2003). These urban spaces are characterized by elements of townscape (Cullen, 1961; Cullen, 1967; Taylor, 1999), urban elements (Lynch, 1960; Jacobs, 1961) or urban patterns (Alexander, et al., 1977; Alexander, C. (1979). CIM has to create a digital platform to enable these multiple scales and enable designing. Designing can be understood as a kind of experimentation and play within design elements in design worlds. Urban designers explore urban phenomena, define urban qualities, identify and tackle urban problems, enter design worlds, recognise and play with design elements, establish rules to combine elements create virtual, digital or physical prototypes, drawings or models and affirm or negate urban designs (Schön, 1984). These experiments are products of imagination that can be addressed, through the notions of
rules, types and worlds (Schön, 1988). There are different types of design elements with rules how to combine and arrange them in space. Some design elements are more static such as streets, plots and buildings. Landscaping elements grow. There are dynamic urban elements such as movement of people and vehicles (Taylor, 1999). Digital technology can allow creating design worlds, visualizing and simulating urban design scenarios. To enable creativity in the design worlds, digital technology must incorporate a toolbox of generic types and rules that are used by urban design professionals.

This paper links typo-morphology, a branch of urban morphology, with procedural modeling of buildings and cities to present a generic morphological structure of urban elements and discusses them as programming classes in CIM. It is very difficult to transpose BIM to CIM. There are no handbooks for urban design, but there are influential papers and books written by Kevin Lynch, Jane Jacobs, Gordon Cullen and Christopher Alexander (Marshall, 2012). Computer scientists usually refer to early work of architects, designers and mathematicians that worked with geometry of architecture and urban environment (March & Steadman, 1971), shape grammars (Stiny, 1980), urban patterns (Alexander et al, 1977) when they create procedural models for generation of buildings and cities (Parish & Müller; 2001; Wonka et al., 2003; Müller, et al; 2008; Vanegas et al., 2012). There are no direct references to the subsequent research in urban morphology. Procedural modeling does not incorporate the newest research in urban morphology on typologies of design elements and procedural typologies. On the other hand, most of the urban morphologists are unaware that procedural modeling exists. They focus on historical studies of cities, often without practical implications for urban design (Sanders & Baker, 2016). Typo-morphologists intuitively identify and abstract urban elements (Moudon, 1997; Marshall, 2015), organize them into a morphological structure (Conzen, 1960; Kropf, 2014), create typologies of design elements and procedural typologies, rules how to combine different elements (e.g. Sanders & Woodward, 2015).

The purpose of this paper is to structure the knowledge of urban morphology and create programming classes for CIM that derive from urban design practice. Procedural modeling has lot of potential if it converges with urban morphological research and serves as digital toolbox for enabling design worlds and designing cities. The current application of procedural modeling is in generating urban scenarios and forecasting urban development. It is either too complex expansion of GIS (e.g. CityEngine is manually edited 3D extension of ArcGIS) or automated urban design machine (the case of Urban Canvas that got integrated in UrbanSim, an urban simulation software). Software as CityEngine lacks the clarity of the toolbox and design elements that are integral part of ArchiCAD or Revit.

LITERATURE REVIEW

**Typo-morphology and morphological structure**

Within urban morphology, there are different approaches and schools (Moudon, 1992; 1997; Kropf, 2009; 2017; Oliveira, 2016). Typo-morphology is an approach that seeks to understand cities and their evolution through classifying urban elements into types. Gianfranco Caniggia, one of the pioneers of typo-morphological approach, argues that cities grow incrementally with many elements being juxtaposed. An understanding of the formation and transformation of cities needs analysis of the mutation of the elements through both time and space (Moudon, 1994, p.292). Pattern language is an example of the typo-morphological approach. The urban patterns consist of a set of elements or symbols and a set of rules for combining these symbols. A set of underlying elements and relationships between elements characterizes an urban pattern: X=r (A, B, C...) where X is type and r shows relationships between elements A, B, C... Each pattern is connected to certain larger patterns that come above it in the language; and to certain smaller patterns that come below it in the language. Even though there are theoretically millions
of combinations between elements, the number of generic patterns is rather small. The rules only allow combining certain elements in a pattern. Only few hundred urban elements and patterns define cities like London or Paris (Alexander, et al., 1977; Alexander, C. 1979).

Typo-morphologists understand cities as a morphological structure of juxtaposed elements. Morphological analysis is based on three principles. Urban form is defined by three fundamental physical elements: buildings and their relation with open spaces, plots and streets. Urban form can be understood at different scales, usually corresponding to the building/plot, the street/city block, the city and region (Moudon, 1997). There are two perspectives on urban form and morphological analysis. One emphasizes combination of two elements: the individual parcel of land, together with its building or buildings and open spaces. Over time, these elements that lie on the plot are either used differently (e.g. by different social classes) transformed physically, eliminated or replaced by new forms. The rate of change in either the function or the form of the plots varies from city to city, but also generally fits into cycles related to the economy and culture. These are referred to as burgage or development cycles (Conzen, 1960; Whitehand, 1987; Moudon, 1997). The other perspective, favoured by Italian architects, centres the street in interplay with the building. The city block is not a group of plots, surrounded by streets, but the street space with its aligning buildings. The street has a position in the hierarchy of scales from smallest architectural scale (the building), urban scale (block or aggregation of blocks along main streets) to largest regional scale (arrangement of neighbourhoods along regional axes) (Caniggia & Maffei, 2001; Kropf, 2013; 2014).

The two perspectives have different viewpoints. The first one that focuses on plots, their development and integration in city blocks looks the city from the top. The other perspective forwarded by Italian architects perceives the city and the building from the street. The city is instead experienced kinaesthetically as sequences of urban spaces (Cullen, 1961; Taylor, 2003). Two approaches in urban design have worked with symbols and urban elements to combine these perspectives to understand urban experience and experiential qualities of urban environments and represent them on maps. Kevin Lynch (1960) conceptualized five urban elements: paths, edges, nodes, districts and landmarks. People orient themselves by moving along major paths and landmarks. They create mental maps of major and minor paths in respect to edges (impermeable transportation infrastructures, waterfronts, etc.) and landmarks. Gordon Cullen (1961) analyses sequence of images (serial visions) along pedestrian paths. He also represents the elements in each image with symbols on a map. The focus of the serial vision is the path, but it is defined by surrounding buildings and landmarks (what pedestrians see at the viewpoints). In contrast to Lynch, who focuses on imagibility of these urban elements that pedestrian sees, Cullen (1967) looks at their character, scales and complexity.

Within Lynch’s tradition of urban elements, there is a more detailed urban design approach that focuses (like in the Muratorian typo-morphological tradition) on street spaces and the city block-street frontages (Figure 2). This symbolic representation shows elevations of building façades and interactions of neighbours (Appleyard, 1981)
Kropf (2014) fuses the Conzenian and Muratorian typo-morphological traditions and opens the discussions on a generic morphological structure. His review embeds street space (Caniggia’s city block) in the morphological hierarchy of street, lot and building that expands to urban block and a morphological district.

This morphological structure does not consider edges. The combination of the Conzenian and Muratorian typo-morphological traditions with Kevin Lynch’s urban elements and Gordon Cullen’s indicators produces a generic morphological structure (Figure 3). It is also important for CIM to consider symbolic representations at larger scales. This needs a topological understanding of relationships between neighbourhoods (Figure 4), but also between the underlying elements such as the interaction between streets and buildings. This requires an algebraic approach that is deeply rooted today in urban and transportation modeling. The focus is on generalization if spaces as centroids, locations defined by urban activity and land use (McLaughlin, 1969).

**Geographic Information Systems (GIS) and Building Information Modelling (BIM) classes**

There are two fundamental ways of representing physical geography in GIS (Longley et al. 2005). The first way is to superpose the Earth with an orthogonal grid, tessellated into cells. Each cell or area in the Earth’s mosaic is differentiated, categorized and attributed with one variable. The second way is to pin discrete objects on the Earth’s surface or reference them with geographic information and position. The discrete objects are represented by 2D shapes (points, polylines and polygons) and are attributed with multiple variables. The discrete objects and the variables are organized in attribute tables as rows and columns. These two geographic representations in GIS and in 2D computer graphics are known as raster and vector graphics. GIS vector graphics represent geographical features as points, lines and polygons with attribute tables. GIS is generically 2D
environment. There is no topological representation of geographical features. The advantage of the 2D geometric representation of symbols based on attributes allows for quick visualization (Figure 5).

BIM, for example the Industry Foundation Classes (IFC) data model, describes buildings and building elements as industrial products. BIM is a generic 3D environment based on objects (products). The different with the GIS is the inheritance. Each BIM product is an element with placement in a 3D environment and multiple representations. BIM is an object/element oriented. Different kinds of elements are places on building storeys that are aggregated in a building (Figure 6).

Figure 7 illustrates the elements and relationships in CIM.

CIM inherits the generic 3D environment and representations from BIM, just in a context of a morphological structure from Figure 2. The existing GIS do not incorporate the generic morphological structure, whereas BIM classes cover just a part of it. Figure 7 does not include landscape elements or analytical elements important for urban design (see elements of townscapes in Taylor, 1999). It is conceived and presented conceptually. It is contributed by a representation of a hybrid drawing board (a top-within perspective) that reveals building façades on a plan (Figure 8).

DISCUSSIONS
The morphological structure and its elements can be understood as programming classes in CIM as a 3D virtual environment. This is not common perspective on cities neither for urban morphologists nor for urban modellers. The knowledge from urban morphology is qualitative and descriptive. It comes as libraries of typical design elements and urban patterns. Urban morphologies aim to understand generic morphological structures, but their theories do not always link to urban design practice. Many morphologists argue for morphologically informed urban design. CIM can contribute in creation of digital urban elements and pattern typologies. One of the hindrances is lack of software to enable this. Figure 7 shows a conceptualization that can help programmers and procedural modellers to structure a 3D virtual environment that corresponds to the toolboxes of urban designers (Figure 2, morphological structure in Kropf, 2014; elements of townscapes in Taylor, 1999).

Urban design, procedural modelling and city visualization have different purposes (Figure 9), but they share the same interest in three-dimensional understanding of cities. Urban design aims to create and shape urban spaces usually by juxtaposing different design elements (that can derive from morphological research). Procedural modellers tend to create generic procedures to create cities. They build design machines or automated architects (discussed by Negroponte, 1970; Cross, 1976; Batty, 2013). Procedural modelling is mainly used in computer graphics and gaming. Slowly it moves to the domain of practical urban design. Autodesk have advertised Urban Canvas, procedural modelling, as software helps planning professionals more effectively create and communicate urban plans and designs, with easy to use design and analytical tools. As such, it becomes part of urban modelling that aims towards computer generated urban design (Figure 5). Procedural modelling is also used in visualization (e.g. Biljecki et al., 2017). CityGML is an open standardized data model and exchange format to store digital 3D models of cities and landscapes (www.citygml.org). It introduces a Level of Detail (LOD) concept. A complex set of five LODs in CityGML 2.0, and 15 newly proposed LODs (Biljecki et al., 2016) is very important for visualization or simulations, but does not fulfil the needs for urban designers or planners who work with elements in 2D (comprehensive plans) or 3D (detailed plans). 3D city visualization does not focus on specific design elements to play with.

CONCLUSIONS
This paper reviews research in urban morphology, class conceptualization behind BIM and 3D visualization and procedural modelling to present a proposal
Figure 5
GIS classes

```
Point
{ XCoordinate;
  YCoordinate;
}

Polygon
{ BoundingBox[4];
  NumberOfParts;
  NumberOfPoints;
  AllParts[NumberOfParts];
  Point[NumberOfPoints];
}

MultiPoint
{ BoundingBox[4];
  NumberOfPoints;
  Point[NumberOfPoints];
}

PolyLine
{ BoundingBox[4];
  NumberOfParts;
  NumberOfPoints;
  AllParts[NumberOfParts];
  Point[NumberOfPoints];
}
```

Figure 6
Building Information Modelling (BIM) classes and product class and its representations (based on the IFC data model)
Figure 7
CIM programming classes

Figure 8
CIM perspectives and drawing board (top skewed perspective)
for morphological structure and design elements of CIM as programming classes. It focuses and discusses implication for practical urban design. Procedural modellers aim to generate urban designs, simulate and visualize cities. The urban models historically failed in accurately predicting future urban development patterns. This is not a problem with bad models, but there are too many random sequences of future events that it is impossible to predict future urban patterns. There is a risk that the enthusiasm for procedural models disappears as predictions fail. However, procedural modelling has lot of potential to converge with urban morphological research and serve as digital background for designing cities and CIM.

CIM aims to create a platform where urban morphologists and urban designers can share libraries as typologies of urban design elements and patterns. It is conceptually conceived as a software for design of urban 3D models. The idea of computer generated cities and urban modelling has been heavily criticized as predictive tool, but it has a future as background for urban analytics. In a same context of urban analytics, CIM should store this qualitative information about urban patterns and inform urban designers before predict and generate cities.

Many morphologists do research on urban patterns and elements. Many of them argue for morphologically informed urban design. To make morphologically informed urban design possible, there is a need of digital tools and software that will store this information and allow urban designers to work with it. CIM is conceived as digital tool that can help with practical urban design. The future research aims to develop CIM as 3D virtual environment and create toolbox with generic urban design elements.

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