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URBAN MORPHOLOGY AND CITY INFORMATION MODELING (CIM) – COMPUTATIONAL URBAN DESIGN IN THE PLANNERS' OFFICE OF THE FUTURE

Abstract

City Information Modelling (CIM) seeks to evolve Building Information Modelling (BIM) into urban planning and design practices that are today dominated by Geographic Information Systems (GIS). The design toolbox in GIS software does not relate to urban design elements (streets, sidewalks, buildings, lots, etc.) or urbanist parameters. Urban designers must use geometric design elements from GIS (lines, polygons, and points) that do not correspond to their practices and three-dimensional (3D) understanding of cities. This paper explores the CIM framework thought evolution of the architects' and the planners' office, the history, and new trends in digitalisation of urban planning and design from a perspective of urban designer and morphological structure of cities.

Keywords: urbanism, urban design, urban morphology, city information modeling, computational urban design,

УРБАНА МОРФОЛОГИЈА И ИНФОРМАЦИОНО МОДЕЛИРАЊЕ ГРАДА (ЦИМ) – КОМПЈУТЕРСКИ УРБАН ДИЗАЈН У КАНЦЕЛАРИЈИ БУДУЋНОСТИ ГРАДСКИХ ПЛАНЕРА

Сажетак

Информационо моделирање града (ЦИМ) настоји да еволуира Информационо моделирање зграда (БИМ) којима данас доминирају Географски информациони системи (ГИС). Пакет алата за пројектовање у ГИС софтверу не подржава елементе урбаног дизајна (улице, зграде, парцеле, итд.) ни урбанистичке параметре. Урбани дизајнери морају да користе геометријске елементе дизајна из ГИС-а (линије, полигоне и тачке) који не одговарају њиховој пракси и тродимензионалном (3Д) разумевању градова. Овај рад истражује мисаону еволуцију ЦИМ оквира канцеларије архитеката и планера, историју и нове трендове у дигитализацији урбаног планирања и дизајна из перспективе урбаног дизајнера и морфолошке структуре градова.

Кључне ријечи: урбанизам, урбанистички дизајн, урбана морфологија, информационо моделовање града, компјутерски урбан дизајн

1. INTRODUCTION

With the new developments in Information and Communication Technology (ICT), and the increased processing power, storage capacity, and communication bandwidth, as well as accelerated digitalization of organizations and companies, businesses and services, the vision of ubiquitous computing (Weiser, 1991) becomes closer to reality today [1]. City Information Modeling (CIM) seeks to digitalize urban planning and design practices [2-4]. Digitization is defined as the process of converting analogue data into a digital form, and ultimately into binary digits. Digitalization describes diverse sociotechnical phenomena and processes of adopting and using ICT technologies [1]. Urban planning and design processes are dominated by Geographic Information Systems (GIS) and Computer Aided Design (CAD) software. GIS and CAD software developed in the 1960s with a two-dimensional (2D) drawing board and design toolbox of geometric elements (points, lines, arcs, polygons, etc.) that has not changed much as data structure and design capabilities. Urban planners and designers remain reluctant to digitalization [4]. Urban planners typically negotiate development projects in various constellations of actors and stakeholders. They typically are not GISers and CADers, but they use the inputs of GIS experts and spatial analysts (GISers refer to technical professionals that use GIS for spatial analyses). GIS and CAD work perfectly for creating maps of cities and urban plans with streets, buildings and plots as polylines and polygons, for spatial database, or for 2D spatial and morphological analyses [5-6], but GIS and CAD cannot represent the hierarchical morphological structure of urban design elements (streets, sidewalks, buildings, lots, etc.) and their interactions in three dimensions (3D).

Urban designers as practitioners must deliver drawings and illustrations of cities and develop design codes or guidelines at various stages of planning and urban design. Masterplans are the standard deliveries to communicate urban design, but urban designers have the unique competence to analyse the experiential qualities of cities in 3D [7]. Furthermore, many urban designers use sketching and the typical computer mouse as interface works differently than the pencil or pan in the hand. Faced with a choice between GIS and CAD, they often return to hand drawing and sketching, and they combine images, diagrams, and maps from diverse software packages to illustrate the experiential qualities, to analyse and to design cities. Urban designers understand cities through types and typologies [6, 8-13]. Types are abstractions about urban forms, or the representative exemplars or prototypes. Society creates types of streets, buildings, neighbourhoods, cities, etc. (even types of spaceships, space colonies, etc.) to simplify communication and promote values [14]. A type packs much information into one icon: a set of architectural or environmental attributes; a set of rules for construction and for organization of space; a set of behaviours and defined roles that take place within it; and a set of qualities it should exhibit [15-16]. Urban morphologists describe cities as a hierarchy of design elements that create types: streets and their layout, plots and their aggregation in blocks, buildings, and land uses [5, 13]. Urban morphology inferences and interprets types of buildings, streets, neighbourhoods etc., whereas urban design invents types and prescribes interventions using types [17]. Urban designers typically turn typologies into design guidelines or Form-Based Codes (FBCs) [6, 12, 18-23] often with morphological methods.

This paper explores the history and new trends in digitalization of urban planning and design from a perspective of urban designer and morphological structure of cities [5, 13]. It described a framework for City Information Modelling (CIM) as evolution of Building Information Modelling (BIM) into urban planning and design that is today dominated by GIS and CAD. The paper furthermore looks at the evolution of the architects' and the planners' office. CIM is conceived as a digital tool in the planners' office of the future that will address the needs of urban designers for morphological hierarchical understanding of cities in 3D. BIM apps replaced CAD software in the architects' office because BIM standardized around the floor plan as a drawing board and a design toolbox closely aligned to the design elements in architectural practices (walls, windows, doors, furniture, etc.). In the BIM apps, architects arrange architectural elements on a floor plan. GIS software does not have a design toolbox that relates to urban design elements (streets, sidewalks, buildings, lots, etc.) or urbanist parameters such as Floor Space Indexes (FSI), Open Space Indexes (OSI), etc. or the morphological structure of cities (hierarchy of streets, lots, and building). To adapt to the GIS and CAD apps, urban designers must use design toolboxes with geometric design elements (lines, polygons, points, etc.) that do not correspond to their practices and three-dimensional understanding of cities. By presenting the CIM framework and its morphological theories, this paper aims to inspire a debate about digitalization of urban planning and design inspired by morphological research and theory and to contribute to increased use of digital tools among urban planners and designers.

2. DIGITALIZATION IN URBAN PLANNING AND DESIGN AND SMART SUSTAINABILITY

Digitalisation in urban planning and design is intertwined with cities and sustainability. In the concept of sustainable development, the urban challenge includes world cities with global reach that draw resources from distant lands, with enormous aggregate impacts on the ecosystems of those lands. Agenda 2030 sets an action plan with sustainable development goals (SDGs) and targets. The mission of SDG 11 is to make cities and human settlements inclusive, safe, resilient, and sustainable. European Commission acknowledges Agenda 2030 in the European Green Deal that highlights climate neutrality, energy and resource efficiency, smart and sustainable mobility, circular economy and preserving and restoring ecosystems and biodiversity and targets disruptive innovation and digital technology as enablers for greater sustainability. Sustainable urbanism addresses the urban challenge in sustainable development with innovative urban design emphasising the human scale and the liveable city, the physical form, and experiential qualities contextualised in world cities shaped by globalisation and virtual-physical existence [23-37]

Digital technology and sustainable development meet in the paradigm of smart sustainability. Smart sustainability inspires and explores the development of smart-sustainable neighbourhoods, digitalization of urban infrastructure and development processes, as well as collaborative experimentation with digital technologies [38]. The aspects of smart sustainability include smart cities and digitalization of urban planning and design practices. The smart city narratives range from embedding hardware and software in the physical city to the effects of computation on the physicality of the city [29]. The smart city has existed as the “informational city” [23], “invisible city” [25], “city of bits” [30], “computable city” [27], “programmable city” [35], etc. The smart city has a physical appearance (hardware such as cables, chips, sensors, robots, and so on), an invisible programming and computing domain (codespace as backend) and a perceptual virtual frontend as apps and social media (so-called cyberspace or metaverse). The digitalization of urban planning and design practices can be understood as digitization of cities (turning analogue data into a digital form and developing data structures as backend) and developing software for urban planners and designers that can be used in urban planning and development as frontend. There are a variety of professionals within urban planning and design that work with sustainability (within or out of the digitalization processes) that have specific digitization and digitalization needs. Strategic planners produce and negotiate visions, frame problems and challenges usually at larger scales from neighbourhood to metropolitan areas. They create policy documents with sustainability goals to be reached typically in long term. The ongoing paradigm in strategic planning is collaborative, communicative, or participatory planning that revolves around information, communicative rationality, and action, consensus building and collaboration among actors and stakeholders [39] discusses three collaborative, communicative or participatory planning streams. For theorists and practitioners of consensus building (e.g. Judith Innes) consensus must be won through negotiation and mediation between interests (and types of information). For collaborative theorists (e.g. Patsy Healey) consensus is potentially inherent in the act of communication between stakeholders. Radical urbanists and architects (e.g. Leonie Sandercock) argue that the aim is not consensus at any price, but empowerment of the most disadvantaged in society. Strategic planning can be applied for any visionary or futuristic thought including cities and strategic urban planners typically do collages of images (in 2D design software) and write documents (in word processors). Physical planners and urban designers focus specifically on the physical form of cities, and they draw plans either in GIS, CAD, or BIM. Physical planners work with zoning or density of development in 2D by arranging land uses at a scale of lots or neighbourhoods (and CAD and GIS fulfill their needs). Urban designers focus on physical form in 3D and experiential qualities of urban space, at a street, city block or neighbourhood design level [7]. There are also landscape architects, transport planners and traffic engineers, mobility managers, etc. that work with cities. In the different practices and needs for professional software, GIS emerges as an integrating framework to share and work with urban data. GIS and spatial analyses are (smart city) digital tools to address sustainable urbanism. To understand the necessary level of GIS expertise for a specific interdisciplinary research project, Ricket [40-41] identify three roles of GISers: 1) use of GIS as a Tool, 2) employing a GIS Toolmaker for commissioned applications or 3) a GIScientist for developing and programming new forms of spatial analyses (Figure 1), but there are also many urban planners and designers that are nonGISers. There are limitations in applying GIS and spatial analysis. Spatial analysis is not particularly useful in analyzing urban planning processes or causal understanding (graphs and topologies) beyond the specifications of identified problems [42]. There is also a drift between GISers or nonGISers. Many public authorities and private business have GIS divisions that deal with spatial data and land cadastres (GISers of various sorts as shown on Figure 1), that sit separately from city planners and urban designers (predominantly nonGISers) that negotiate development and draw plans. The GIS divisions seek to address the challenges associated with processing large datasets and spatial data infrastructure of the municipalities, and the urban planners focus on planning processes and urban development. There is a need to bridge the gap and reach out to nonGISers with a new kind of software.

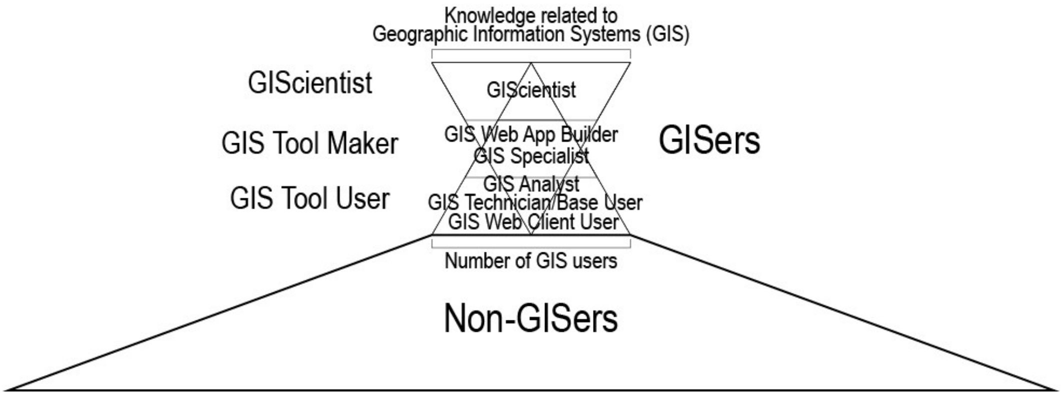

Figure 1. The GISers (the top of the figure is drawn by Ricket, et al. 2020) are just a technical segment of the professionals involved in urban planning and design. There are GIS departments in public authorities or private businesses and planning consultancies. Typically, GISers (as well as CADers and BIMers) are technicians that sit separately, whereas most urban planners and designers are typically nonGISers (many are not even GIS Tool Users as shown above) and they belong to separate departments.

3. THE DEVELOPMENT OF DIGITAL TOOLS FOR URBAN PLANNERS AND DESIGNERS

To understand the dominance of CAD and GIS in today's urban planning and design, and BIM in architecture it is important to look at the history of software and the process of digitalization of the architect's and urban planner's office. The vision for the (digital) office of the future was laid by Vannevar Bush's paper "As we may think" as the concept of "memex". A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility (memex includes all the converging aspect in ICT today, the personal computer, smart communication device and artificial intelligence). It is an enlarged supplement of human memory or "an extended mind" [43-44]. The extended mind includes various portable, wearable, or tangible devices and interfaces, transparent technologies and various apps and online worlds (Internet, social media, etc.) building a cyberspace or metaverse. Some devices, interfaces and virtual representations work smoothly, e.g. the software for word processing is widely used. Human society experienced digital transformation towards virtual paper and keyboard input. Keybords and typewriting are so widespread today that many children prefer typing over handwriting. But architectural professionals, urban planners and designers who previously drew by hand, with T-squares and triangles, did not experience a complete digital revolution. They adapted to a new way of thinking about architecture and cities. The use of digital tools such as CAD and GIS software in urban planning and design is linked with technical knowledge for doing spatial analysis and individual preferences to use computers (of CADers, BIMers, and GISers). Even though architectural professionals, urban planners and designers are trained in CAD, BIM and GIS, there is a misfit between urban planning and design practices and available software. The computers feel peripheral to cities, urban planning and design and the conceptual frameworks of CAD and GIS coerce urban planners and designers in thinking in geometric and database terms that are very limited representationally. CAD and GIS changed very little from their origins in the 1960s.

Digitalization is driven by technological revolutions as Informational Technologies (IT) and Communication Technologies (CT) develop and intertwine with society [1]. IT and CT developed and merged in the 1990s with the expansion of the Internet and spread in society with smart phones in the 2000s. The origins of ICT are much earlier, and CAD was one of the first applications of IT.

After World War 2, the Advanced Research Projects Agency (ARPA) and National Aeronautics and Space Administration (NASA) supported pioneering research on ICT. The Internet (or networking computers) experiments started in the 1960s when J. C. R. Licklider became director in ARPA. Inspired by Vannevar Bush, J. C. R. Licklider conceptualized "human-machine symbiosis" [45] and he coined the term "computer-aided", describing theoretically systems for computer-aided planning and design. As director at ARPA, J. C. R. Licklider supported, financed, and supervised research on "human-machine symbiosis" systems, or Human Computer Interaction (HCI). Ivan Sutherland [46] using a grant from ARPA demonstrated Sketchpad, the first Computer Aided Design (CAD) system at Massachusetts Institute of Technology (MIT) as a human-computer communication system using the TX-2 computer at MIT Lincoln Laboratory. Timothy E. Johnson presented Sketchpad III in 1963 too, as a CAD system that could create 3D designs. The computational models and computer graphics concepts from Sketchpad for representing points, lines, arcs, and surfaces remain until today. In the same time Douglas Engelbart (known as the "father of the computer mouse") also financed by ARPA and NASA developed HCI theories, hardware, and software for "computer-aided working space" or "human augmentation" in the (digital) office of the future. Douglas Engelbart envisioned the office of the future in the 1960s as a working station, a terminal that links to a mainframe computer. While in Sketchpad the human designer communicated with the computer with light pen on the screen that acted as electronic drawing board, Engelbart used a keyboard and computer mouse with a pointer. In Sketchpad, there was a design toolbox with lines, arcs, and surfaces as hardware complement, whereas Engelbart instead of a design toolbox offered programming classes for anything that was displayed on the screen. Similar direction of graphical pursued the RAND cooperation with the GRAIL (GRAphical Input Language) on the Linc minicomputer (that is considered as a predecessor of the personal computers today). GRAIL was an interactive software-hardware system that utilized visual programming for elements displayed on the screen. It allowed a human to write on a two-dimensional surface with a stylus and the system recognized the text and the diagrams written on the tablet automatically.

In the 1970s, the pioneering efforts to create hardware-software systems for "human-machine symbiosis" and "human augmentation" converged in the innovations and developments in PARC (Palo Alto Research Center) that was established by Xerox to digitize photocopying and printing. Office automation became the buzzword used to describe the computer augmentation of office functions in the 1970s. Psychological research into human interaction with computers gave rise to the field of HCI by the research in PARC. Robert W. Taylor, who like Licklider and Sutherland directed ARPA's center for computer research became a director in PARC in the 1970s. Taylor recruited a new generation of computer scientists and programmers and fashioned a prototype for ITC working environment in PARC that will shape Silicon Valley until today. Taylor recruited visionaries as Alan Kay, Charles P. Thacker, Charles Simonyi, etc. and created a cozy and informal working environment that revolved around ubiquitous computing, personal computers (Xerox Alto) and local area networking (Ethernet), mouse-driven Graphical User Interface (GUI), virtual paper and word processing, and the desktop paradigm through object-oriented programming (Smalltalk language). Alan Kay promoted the desktop metaphor as files, folders and windows in the experimental Xerox Alto inspired by Engelbart's mouse and GRAIL's display elements. Charles Simonyi developed the concept of virtual paper and Bravo, the word processor that became crucial for the widespread use of Microsoft Office. The desktop paradigm mainstreamed with Apple's computers and Microsoft's Windows software in the early 1980s. It is a dominating paradigm that is built over the x86 architecture that was developed by Intel in the 1970s and miniaturized over the years. The widespread diffusion of personal desktop computers with a computer mouse at the end of the 1970s and 1980s (e.g., Apple II, Apple III, and Apple Lisa and x86 series processors by Intel) rendered both the light pen, stylus, and AI obsolete in architectural practices (only until recently when tablets reemerged). By the late 1970s, the computer industry promoted a vision for automating office work, not for stand-alone personal computers, but as office automation systems for networked workstations. The personal computer with the keyboard and mouse became the standard. The CAD systems for architectural systems that established in the 1980s and 1990s (for example Autodesk's AutoCAD) as well as the Building Information Modelling (BIM) software from the 1990s and 2000s (Graphisoft's ArchiCAD and Autodesk's Revit) remain dominant and unchanged conceptually. Unlike Sketchpad or GRAIL, they revolve around Engelbart's mouse pointer and Xerox Alto's office desktop metaphor. Autodesk AutoCAD was released in 1982 and it made it possible to draw architectural projects with lines, arcs, and dimensions with a computer mouse. The mouse and pointer, as well as grid and snap functions recreated the drawing board of architects with the T-square in a digital form. AutoCAD dominated architectural design practices until the emergence and spread of BIM software, namely ArchiCAD (initially developed for Apple Lisa in 1984 and transited to Windows in the mid-1990s) and Autodesk Revit (in the 2000s). The difference between ArchiCAD and AutoCAD was that ArchiCAD used building elements as walls, slabs, doors, windows and so on as 2D symbols on a plan and created various 3D representations (including sections, elevations, architectural details, axonometries and perspectives). ArchiCAD digitized the architectural famous handbook Architects' Data (often called Neufert, by its author Ernst Neufert) in its building elements that do not show only the 2D symbol, but also the spaces needed to operate (e.g., furniture elements in kitchens or bathrooms). ArchiCAD like AutoCAD worked as digital drawing boards, but the difference was that ArchiCAD created sections, elevations, architectural details, axonometric views, and perspectives automatically from the 2D symbols on the plan. In AutoCAD, architects draw sections, elevations, and architectural details manually and they use elevations to create 3D visualizations. However, neither ArchiCAD nor AutoCAD used hand props for sketching as pencils or triangles on the grid and snap digital drawing board. BIM software like ArchiCAD created a plan arranging drawing board that links to the GRAIL display elements paradigm, but this cannot be applied in a context of urban design drawing board and the GDL (Geometric Description Language) never became popular among architects (in a way that visual programming add-on Grasshopper alleviated the 3D modeler Rhino in the digital architect community). The Geographic Information Systems (GIS) software developed two representations: discrete objects (attribute databases for object supported by the vector graphics in CAD) and continuous fields (raster graphics). The GIS software, like CAD, was established with the desktop computer with computer mouse and keyboard. It experienced the commercialization of CAD. AutoCAD launched Autodesk into leading CAD software company from the 1980s until today and ArcGIS similarly put ESRI in a dominating position. Like CAD, GIS has an editor with geometric elements (points, lines, and polygons) and it is widely used for drawing 2D masterplans.

City Information Modelling (CIM) starts with Geographic Information Systems (GIS) and brings a perspective of city planning and urban design as a specific niche of consumers of GIS software and spatial media. GIS cannot represent morphological structure with interactions between elements or typologies. CIM problematizes GIS as data structure, by conceptualising a more complex data structure than raster and vector data. CIM like BIM should store information about cities in a hierarchical morphological structure of streets, lots, and building (as well as interactions street-lot, lot-lot, lot-building, street-building). The hierarchy in BIM is standardized as Industry Foundry Classes (IFC) data. IFC data shows a graph of all building elements in a room or on a building story as a numbered list. The GIS data structure includes geometric elements and shapes as classes defined by integers (as geospatial coordinates) and linked to a database with integer and string variables (raster data is integrated in the map as array of integers). There are two directions of CIM research. Gil (2020) reflects CIM in a context of digital tools for urban planning and design as convergences with GIS, BIM and CIM. The first direction of CIM argues for creating information models that derives from GIS and CIM software that generates urban designs (inspired by the shape grammars of George Stiny) [47] and the second stream develops CIM software as digital tool for urban designers based on practices [2-4]. Within the second direction the emphasis is also on drawing boards and morphogenesis of digital tools where GIS is dominating the practices, but also not fully integrated in city planning and urban design. In parallel, Kitchin [39] discusses 3D spatial media and advancements to 3D GIS.

There are additional computational conceptualisations and data structures for hierarchical 3D modelling from the geospatial and geoinformatics branch and from video games and animated movies that use the concept of "scene graphs" in 3D modelling. The Open Geospatial Consortium (OGC) is an international organization that emerged in the 1990s and developed open-source GIS software as an alternative to commercial packages such as ArcGIS by ESRI. OGL compiles a list of standards for geospatial data. Geography Markup Language (GML) and City Geography Markup Language (CityGML) utilizes markup to create a hierarchical (morphological) structure of geography and cities [48-52] with syntax inspired by HTML (HyperText Markup Language) and XML (Extensible Markup Language). XML is a markup language without predefined tags to use. Geographic Markup Language (GML) utilizes generic geometric elements (points, lines, and polygons defined by gml:coordinates) to create 3D geometry and assign textures. CityGML defines feature classes and attributes (e.g. CityObject/Building/BuildingPart/lod1Solid/Polygon/Surface). The hierarchy of the urban elements is created in the markup code with xlink:href. The 3D geometry of the city is represented at various Levels of Detail (LOD0 to LOD4). CityGML uses generic city objects and generic attributes that can be extended with additional attributes within the markup code hierarchy. The generic elements are Building, CityFurniture, CityObjectGroup, LandUse, Relief, Transportation, Vegetation and WaterBody [50] and they do not correspond to the morphological structure of cities. Secondly, the markups for the object in CityGML are very long and the parameters of the objects are lost in the extensive description of classes. CityJSON emerged as a more concise alternative to CityGML. CityJSON is a data exchange format for digital 3D models of cities and landscapes that is a JavaScript Object Notation (JSON)-based encoding of CityGML. The aim of CityJSON is to offer an alternative to the GML encoding of CityGML, which can be extensive and complex to read and manipulate. CityJSON aims to be easy-to-use, both for reading datasets and for creating them. CityJSON is designed with programmers in mind with JavaScript being concise and popular programming language particularly for browser content and the Internet. The third popular standard of OGC is 3D Tiles that link to development of WebGL and glTF for video games in the 2010s. WebGL is a JavaScript framework designed for rendering interactive 2D and 3D graphics within web browsers. It creates possibilities to develop 2D and 3D video games in browsers, but it also allows to model architecture and cities. glTF is the standard file format for 3D scenes and models (as scene graphs). WebGL and glTF were developed and are maintained and updated by the Khronos Group, a consortium of IT companies that work with computer graphics. 3D Tiles is a standard for 3D geospatial datasets such as point clouds, buildings, and photogrammetry. Built on glTF and other 3D data types, 3D Tiles is a streamable, optimized format designed to tap the potential of 3D geospatial data. 3D Tiles is maintained and updated by Cesium, a private company. WebGL, glTF and 3D Tiles are all JSON based frameworks. There is also Universal Scene Description (USD) framework for interchange of 3D computer graphics data that was adopted by nVIDIA, the giant in production of computer graphics processors or Graphical Processing Units (GPU). USD was developed by Pixar as format to exchange 3D data for animated movies from various sources and it borrows syntax from LISP (an abbreviation of "list processing"). USD uses definitions such as "def Xform "Parent"" and "def Mesh "Child1"" within in large brackets {} to create a scene graph of objects (meshes, forms, cameras, animation paths, etc.) in a 3D scene. LISP creates hierarchical data structure by placing objects/classes in brackets. Every object/class in the brackets is a subordinate e.g. (parent (child)). To define a morphological structure of cities, the syntax would be: city1(neighborhood1(street1(lot1(building1, building 2…))))).

The digital tools for urban planning and development emerged in the 1960s and since the 1990s, computers are widespread in public administrations and businesses that work with urban development (as in any office work). In the architect's office, the drawing board, T-square, and triangles, were replaced by computers with large screens, CAD and BIM apps (often supported by 2D and 3D modelling software), a mouse and a keyboard as Douglas Engelbart envisioned the office of the future in the 1960s. One difference is that Engelbart's idea was to have working stations, interfaces that link to a mainframe computer/cloud as ICT system. Today in the offices there are personal computers that are networked and sometime use cloud services to network teammates, but the processing is decentralized in many microcomputers (as architects grew accustomed to individualized CAD and BIM apps, often off the cloud). In the planner's office the computers are mostly used for preparing documentation and word processing, and the GIS software is typically used in the land cadastre and GIS divisions of public authorities and municipality. Architects and urban designers can sit in planner's offices and use CAD, BIM, and GIS software to draw masterplans, but the apps need to be adapted to the practices, or the urban design solutions must fit the conceptual frameworks and data structure of points, lines, and polygons (that works just for 2D masterplans).

4. BEYOND THE MASTERPLAN

Urban designers as practitioners must deliver drawings and illustrations of cities and develop design codes or guidelines at various stages of planning and urban design. They conventionally use traditional design skills like hand drawing or creating scale models and many urban designers remain reluctant to digitization because it is more difficult to draw with a mouse. The mouse behaves differently on the screen. Small quick movements speed the movement of the cursor, whereas pencil in the hand has a uniform movement speed. The grab of the mouse is not as precise as pencil and paper. Urban designers collaborate with public authorities, private developers, and citizens on coordination meetings, planning workshops and design charrettes, sit around a table, sketch, cut cardboards, make scale models of buildings, and place them on the map. The knowledge and expression of urban designers is diagrammatic [53]. Urban designers not only mix imagery, typologies, diagrams, and mapping in analysing and designing cities, but they develop representations and notations. Kevin Lynch created mental maps with urban elements. Gordon Cullen devised notations and symbologies to describe the experience of urban space. Jan Gehl, [54-55] inspired by proxemics research [56-57] illustrated personal spaces with images at various distances and developed diagrams for analysing human perception between buildings (accentuating street profiles). Street frontages as collages of building façades are also typically analysed by urban designers [58-61]. Urban designers in practice commonly combine theories and representations for urban analyses.

Following these eclectic traditions of urban designers, the CIM framework seeks to go beyond the masterplan and complement it with additional drawing boards that includes a 2D distorted representation of street space surrounded by street profiles and street frontages. Figure 2A shows the hierarchical structure of cities: streets and their layout, plots and their aggregation in blocks, buildings, and land uses as building utilization [13]. Figure 2A highlights the visually perceivable elements in the morphological structure and Figure 2B shows the corresponding representations (plans, street frontages or building elevations and street profiles that become axonometries). Urban designers shift between the building view conventionally described with urban sketches or photographs (Figure 2C1) and a top view of maps and master plans (Figure 2C2). The Italian typo-morphological tradition analyses the city as a network of routes and streets and typologies of buildings (including building plans and façades, [8]). The buildings and plots adjacent to routes and streets on plan create a townscape in three dimensions as an envelope viewed from above revealing the building façades (Figure 2C3). The 3D-to-2D diagrammatic projection of the urban (space) envelope creates an urban experience of a flâneur standing on the street corner observing an aural townscape in 360 degrees. The urban envelope allows an analysis of the interaction between the streets and squares with the surrounding buildings and the design of these interactions. The street frontage or the façade of the city block (called also pertinent strip, [8]) becomes an additional fundamental (edge) element of urban form (complementing the building footprint). Research in urban morphology focuses on elements as objects that are bounded with polygons (building and plots) or extend along axes (streets) while transitional edges such as sidewalks, urban façades, fences, etc. can be permeable, invisible, or dislocated (buildings by setback). These edges as transitional spaces between morphological elements often define the experiential character of urban space.

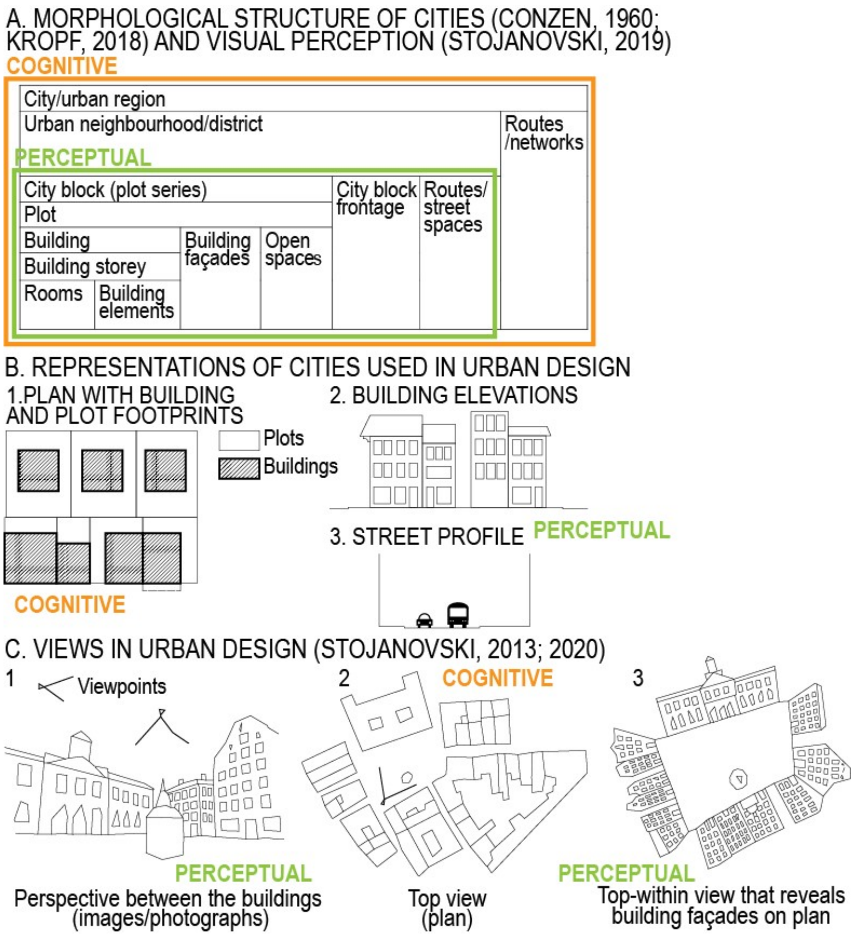

Figure 2. From cognitive maps to perceptual urban (space) envelopes.

Masterplans are the standard to communicate urban design. Figure 3A shows a typical masterplan with conventional zoning and land uses. The drawing boards for plans are tables with T-squares and triangles in the architectural studio or a digital window with drawing aids in CAD and GIS. To complement masterplans, urban designers develop design codes and guidelines, based on building or street typologies (Figure 3B). The design codes and guidelines reduce the emphasis on land uses, which often change rapidly, and emphasize the forms of buildings and streets, which are more rigid and long-lasting. They range from strict codes that regulate architectural details to advisory guidelines aiming to educate planners, design consultants and developers about good design principles or specific design objectives [21]. Figure 3C conceptually illustrates the urban envelope as an assembly of building façades and street profiles describing visual townscapes as aural projections and a design board for urban designers complementary to the master plan. It can be used to design street segments in Figure 3C1, intersections (nodes) in Figure 3C2 or squares (public space surrounded by buildings) in Figure 3C3. City Information Modelling (CIM) software is currently programmed based on the urban envelope conceptualization to enable the design or redesign of townscapes [2-4]. The CIM software will utilize cadastral maps from GIS and masterplans to create urban envelopes depicting townscapes procedurally in interaction with actors and stakeholders. Computer technology allows for the visualization of townscapes by the automatic creation of 3D city models from GIS data and cadastral maps (referred to as procedural modelling). CIM is conceived as an addition to GIS and the software includes a toolbox with morphological and typological elements described in FBCs, design codes and guidelines. Urban designers typically focus on street frontages by creating collages of building façades, showing images, or analysing movement on sidewalks [59-62], or the spaces between the buildings (Gehl, [55-56], uses diagrams of humans in a street profile). The urban (space) envelope allows work with building and street types as a (digital) drawing board and it combines two representations of urban spaces, the street frontage and street profile in one drawing board (Figure 2C).

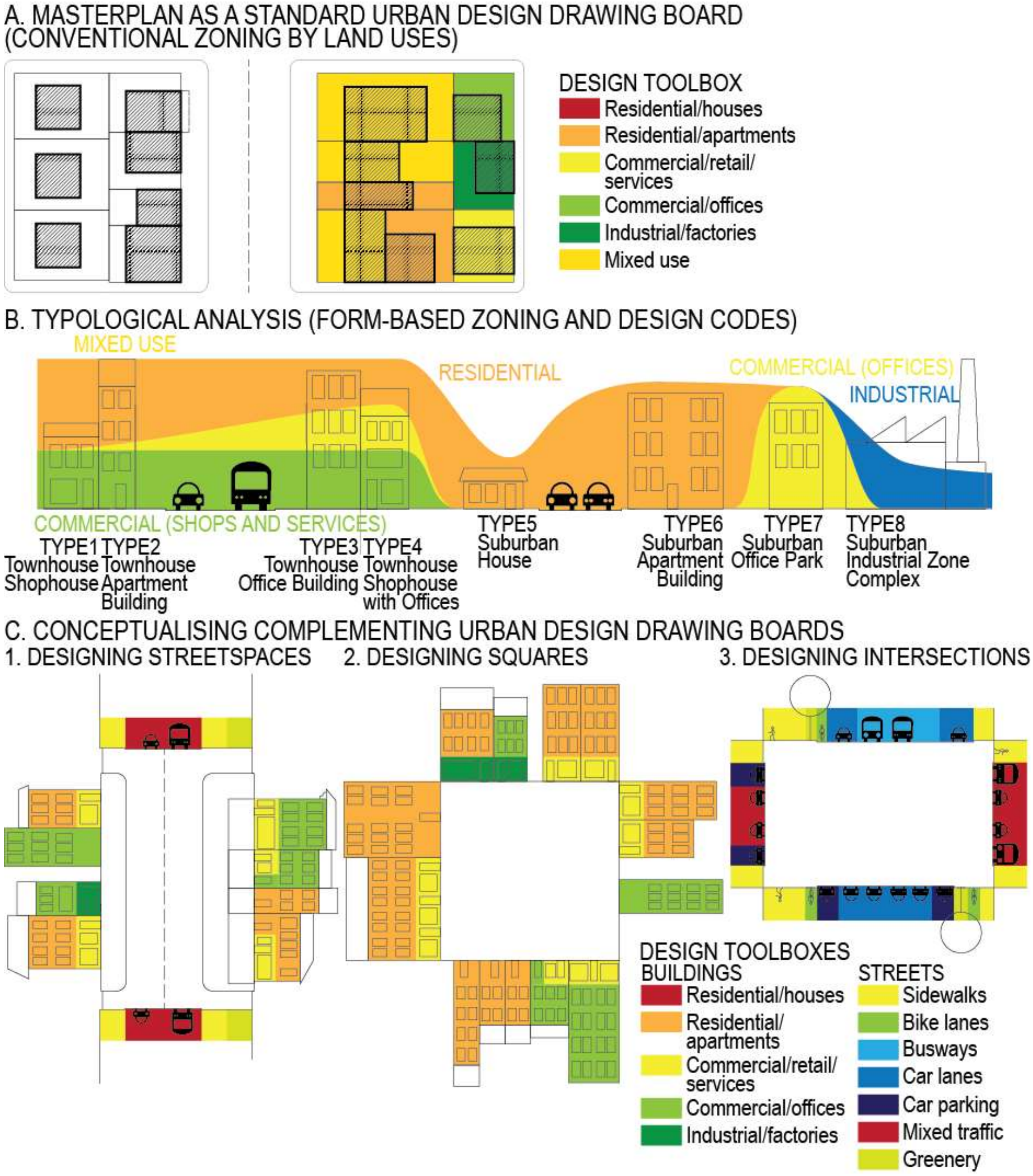

Figure 3. Beyond masterplans- Urban (space) envelopes complement urban design drawing boards.

5. THE PLANNERS' OFFICE OF THE FUTURE (CONCLUSIONS)

Hardware and software intertwine with buildings, streets, even human bodies, seeking to digitalize society and create "smart homes" and "smart cities". CIM framework thought evolution of the architects' and the planners' office, the history, and new trends in digitalization of urban planning and design from a perspective of urban designer and morphological structure of cities. The CIM software aims to contribute to increased use of digital tools among urban planners and designers. The smart city has many names ("informational city", "invisible city", "city of bits", "computable city", "programmable city", etc.) and similarly the architects, urban planners and designers can be "digital", "augmented", "automated", etc. However, urban planners and designers remain reluctant to digitalization similarly as historical cities are rigid to smart technologies. Almost every city has smart city or sustainable neighborhood experiment and many fail to reach digitalization and sustainability goals facing the established urbanist practices and rigidity of historical urbanity (Cugurullo, 2021, refers to these urban experiments as "Frankenstein urbanism"). The digital tools for urban planners and designers such as CAD and GIS, unlike the smart sustainable experiments that seek to intertwine the newest ICT in cities, they rely on proven IT concepts from computer graphics and databases to keep a dominant position. They suffice to draw 2D masterplans. The new generation of hierarchical urban models such as CityGML, CityJSON, 3D Tiles, etc. and new conceptualizations in video games and animation movies such as WebGL and glTF, UDC, etc., offer a great opportunity to develop a new generation of CIM if they integrate morphological theory and develop software for design of urban environments in 3D. The standards first need to align their hierarchy of urban elements in 3D with morphological theory. Without software that utilizes CityGML, CityJSON, 3D Tiles, etc. and links to the cadastral data and GIS it will be impossible to influence urban designer practices. In the end, digitalization must incorporate sustainability concerns in cities and allow to integrate models that assess environmental, economic, and social aspects and contribute to sustainable development.

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