A review of information modelling systems in the built environment

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***Abstract*—The built environment can be described to constitute the surrounding and existing elements created by humans. The systems for modelling information related to the built environment are numerous. Their development are based on varying assumptions and tailored to the various domains in which they are deployed. The functions of these systems are sometimes similar or overlap and they tend to end up with similar acronyms thereby creating confusion to stakeholders in the built environment. As such, stakeholders also find it difficult to choose systems best suited for their needs among the numerous existing ones. A comprehensive record of systems in the built environment with clear definitions of their functions and areas of overlap is therefore necessary to straighten up such confusion and provide requisite understanding among stakeholders. A literature review of information modelling systems in the built environment is therefore proposed. The review examines systems in key sectors of the built environment such the Architectural, Engineering, Construction, Geography and Urban Planning. We conclude that stakeholders should give strong consideration to interoperability needs along the supply chain in which they work while deciding on the choice of information modelling systems to procure.**

Keywords—built environment; information modelling; construction

I. INTRODUCTION AND MOTIVATION

The built environment is defined, from a social perspective, as the human-made space in which people live, work, and recreate on a day-to-day basis [1]. This combines aspects of disciplines such as the visual arts, architecture, engineering, urban planning, real estates, history, interior design, industrial design, geography, environmental studies, law and sociology. Parks, roads, walkways, urban reserved areas, building structures, infrastructures, cities and how they are occupied or used all constitute the built environment. It involves interdisciplinary aspects of design, construction, management and operation of these created surroundings and artefacts mostly associated with the interdisciplinary aspects of the Architectural, Engineering and Construction (AEC) industry and the Geography and Urban Planning industry sectors. Professionals in these domains rely on different systems in the synthesis and management of information associated with the built environment. In recent times, Building Information Modelling (BIM) has been used in the AEC industry sector to manage information on building processes and structures. Offering a parametric object-based representation of elements, BIM is expected to contribute to increasing project efficiencies and reducing project delivery cost and time. As such, efforts are being directed towards extending BIM working approaches to other infrastructures such as bridges, tunnels, roads and water. On the other hand, the Geography and Urban Planning sectors have seen the extensive use of Geographic Information Systems (GIS) and more recently, applications in virtual 3D city modelling in the design and visualisation of urban forms. GIS is suggested to be capable of providing reference for more than 80% of information required in the AEC industry.

Many information modelling systems in the built environment now exist with similar acronyms and functions that are sometimes similar or overlap thereby creating confusion to stakeholders in the built environment. As such, stakeholders in the Architecture, Engineering Construction, Geography and Urban planning find it difficult to choose appropriate systems for their needs. The aim of this review is therefore to provide a comprehensive record of systems in the built environment with clear definitions of their functions and areas of overlap. This will contribute to straightening up confusion among stakeholders and enhance their understanding the functions of existing systems.

This paper is organised as follows. An insight into related works is provided in Section II before presenting the research method in Section III. This sets the stage for Section IV which discusses the information modelling systems in the built environment. Section V presents a classification table with an accompanying brief discussion. Section VI concludes the paper.

II. RELATED WORKS

BIM and GIS have featured a lot in scientific ICT literature in the built environment. One driver of such level of research activity is the industry's quest to intelligently digitize all aspects of the built environment. BIM and GIS/virtual 3D city modelling are tools through which aspects of digitization could be achieved although with quite distinct application levels. BIM deals with micro real world details of building indoor/envelop data using local object/building coordinate system, whereas, GIS uses geographic coordinate systems to model outdoor real world elements at the macro level at varying scales. Traditional GIS is characterized by paring 2D points to create lines/polygons of geographic elements, whereas BIM technology is about building intelligent objects represented by 3D solids and surfaces [2].

The review by Volk et al, [3] reveal that BIM implementation on existing building and related refurbishment works is in infancy and very scarce due to difficulties in the handling of obsolete specification information, uncertain data, unfamiliar objects and associated relations. Reviews on BIM have also analysed aspects of legal implications [4, 5] and the deployment of software systems/tools [6-8] which are increasingly becoming overwhelming in number [8]. On the other hand, some areas of application covered by reviews on GIS include groundwater pollution assessment [9, 10], water resources and hydrologic modelling [11, 12], tourism planning [13] and access to health care [14-16]. Reviews [17, 18] have also been extended to the recent development of 3D city models many of which utilize GIS applications. 3D city models, also termed 'cybertown', 'cybercity', 'virtual city' or 'digital city' [19] are of interest in this paper as they constitute advances drawing on GIS applications with the modelling process, in software environment, being similar to that of BIM.

Shiode [17] made an effort to fit typologies of the varied existing 3D modelling approaches into a coherent structure and based the study on the degree of detail captured/reproduced in models, the types of data input in terms of heights and facades and the degree of functionality. Another study [20] based models on the capability of 3D analysis such as proximity/overlay, spread/flow analysis, 3D density and visibility analysis. In parallel to these, Singh et al's [19] review categorized the approaches into automatic, semi-automatic and manual geomatic techniques, an umbrella term to describe mapping technologies. This study noted that while each technique has its strengths and flaws, the point cloud method is the modern trend in 3D city modelling. While acknowledging that 3D city modelling may have its shortcomings like any other technological development, the application of 3D city modelling has been widely reported in the literature. A comprehensive track record of inferred categories of various reported use can be found in the review by Biljecki et al's [18]. On the integration of BIM and GIS, Zhang et al [2] focused only on the asset management domain and Fosu et al [21] presented a systematic review analysing the distribution of related papers in known journals and conference proceedings spanning 2006 to 2015. The review by Fosu et al [21] identified the management and storage of data resulting from BIM-GIS integrated system as one of the key issues that need addressing. In this paper, we identify existing systems in the built environment and state their various functions including information on interoperability potential in terms of file exchange formats.

III. METHOD

In this paper, we undertook a literature review to explore the recent developments in information modelling integration in the built environment. While there is a myriad of literature on these subjects within this broad domain, a number of terms now exists either as descriptions of standards in the concerned subjects or as acronyms coined to describe developed systems. The key most occurring terms are identified and classified. The primary sources of information in the study are publications from journals, conferences and workshops. Websites, discussion forums and blogs of organisations also served as information sources for analysis.

While many recent research efforts tend to dwell on exploring 3D city models and BIM, they appear to be built on the foundations of GIS and CAD integration. On one hand GIS applications form an integral part of 3D city modelling have struggled with a standard definition as noted in Döllner et al [22] and Biljecki et al [18]. On the other hand CAD capabilities, or at least information exchange utilities for CAD file formats, are embedded in BIM applications.

IV. BUILT ENVIRONMENT INFORMATION MODELLING SYSTEMS

Advances in IT, particularly object-oriented computer programming, has given rise to great improvements in the representation of real life physical elements with their digitized counterpart. It is now possible to incorporate rules and attach attributes to digitized objects in order to bring their behaviour much closer to that of their physical counterparts. Transcending the CAD era of line and vector representation in the built environment (BE), Building Information Modelling (BIM) software applications are now being used to aid the planning, design, construction, operation, retrofitting, reuse and demolition of buildings. Although still undergoing improvements and expansion in scope of application, it is poised to be the latest approach for project delivery and management in the built environment. Thus, the envisaged successes in the BIM approach have triggered similar developments in other BE domains. We now have information modelling applications extended to bridges[17, 23]; known as Bridge Information Modelling (BrIM). Closely related to this is Civil Information Modelling (CIM), termed Civil Engineering Information Modelling (CEIM) in this paper, for the modelling of civil engineering structures [24]. Similarly at urban and regional scale of modelling in the Built Environment, the applications of Geographic Information System (GIS) have metamorphosed into the modelling of 3D virtual cities or 3D city Modelling, herein termed as City Information Modelling (CIM). In this review, we suggest a general term, Built Environment Information Modelling (BEIM) as illustrated in Fig. 1, to encompass information modelling of all such systems used in the built environment. By reason of the objects of modelling, these systems are grouped under buildings, infrastructure and geographic and built elements.

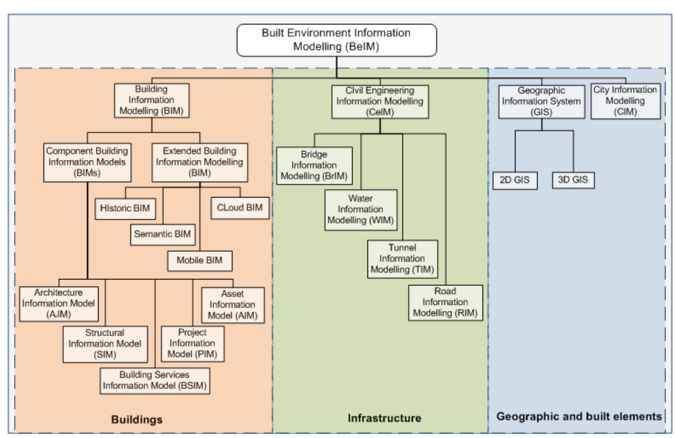

Fig. 1. BEIM systems

A. Building Information Modelling (BIM)

BIM is the emerging object-based system for the representation of building and related data in the construction sector. BIM technology revolves around computer software development and it has been described to encompass processes and people [8]. With the promises of enhancing project efficiency and productivity in the construction sector [25], BIM functions as a tool for enhancing collaborative practices in processes driven by people. The focus of this paper is more on the technology aspect. In BIM, projects are usually based on local coordinate system where building objects can be modelled to fine/high levels of detail. This is a key characteristic of the many BIM applications which exists now. To the interested stakeholders in the industry, the sheer number of available BIM tools presents a challenge of identifying which option of BIM application is more relevant for their businesses among competing alternatives existing within associated professional domains. Since the modelling of buildings is carried out still in the respective existing traditional professional domains (e.g. Architecture, Structural, Facilities, Building Services) building information models (BIMs), an integral component of the comprehensive or federated model, therefore exists for the various functions tied to these domains. Also research efforts have extended BIM applications to a variant of other systems such as the historical assets, and application in web technology and mobile systems.

B. Civil Engineering Information Modelling (CEIM)

CEIM refers to the use of BIM in managing of civil engineering infrastructure facilities besides buildings. This has been earlier termed by Cheng et al [24] as Civil Information Modelling (CIM), which creates some confusion with City Information Modelling in acronym. CEIM covers all major categories of civil works such as bridges, roads, railways, tunnels, airport, ports and harbours, power generation, oil and gas, mining, utility, water and wastewater, dams and canals. Among the various civil engineering infrastructure categories, literature [24] suggests that roads, tunnels and bridges are the most researched in BIM applications. The actions of structural systems in buildings are statically similar to those obtainable in bridges and appear to be a contributory factor to the substantial progress being made in BIM application in this area. This has been termed Bridge Information Modelling (BrIM) and it is also now commonly used in literature [23, 26, 27] to describe parametric object-oriented 3D modelling of bridges. Research activities in BrIM have been further extended by Markiz and Ahmed [28] to the integration of cost estimation hinged on fuzzy logic application. The development of BIM application in other specialty areas in civil engineering infrastructure is eminent. In accordance with areas noted in Cheng et al [24], terms such as Tunnel Information modelling (TIM), Road Information Modelling (RIM), Water Information Modelling (WIM), etc. are developing to describe BIM applications in these respective areas.

C. Geographic Information System (GIS)

The use of automated systems for capturing all types of spatial or geographical data for presentation, storage, manipulation, analysis and management is referred to as GIS [29, 30]. GIS applications allow interactive queries, spatial information analysis, editing of maps and coordinated display of resulting geographic information. GIS representations are possible in 2D (x-y coordinates) and 3D (x-y-z coordinates) respectively referred to as 2D GIS and 3D GIS. For automatic 3D building reconstruction, previously acquired 2D GIS (such as digital cadastral maps) have been part of the sources of data towards the development of consistent 3D datasets [31, 32]. For functions such as network analysis in GIS applications with 3D-GIS capability, navigation is possible only in 2D environment in the interim for finding shortest routes. Thus, 3D navigations in 3D-GIS environment is limited in application and is still being explored by researchers [33].

Deng et al [34] identified three examples of 3D GIS application schemas as Keyhole Markup Language (KML), Collaborative Design Activity (COLLADA) and Geographical Markup Language (GML). These three schemas have been widely used in the IT world. KML is the descriptive language used in Google Earth in storing, transmission, exchange and expression of spatial data [35, 36]. COLLADA , an XML-based utility interchange file format, is used for diverse interactive 3D applications with comprehensive capabilities for visually manipulating sceneries including geometry, shaders and effects, physics, animation, kinematics and the representation of asset's multiple versions [37]. Also XML-based, is the GML Encoding Standard which allows users and developers to vividly describe and exchange generic geographic data sets that contain points, lines and polygons [38]. It is possible to directly refer to elements such as roads, highways, and bridges instead of using points, lines and polygons, and clearly view them in clients and servers with interfaces that implement the OpenGIS® Web Feature Service Interface [38].

D. City Information Modelling (CIM)

In this paper, 3D city model means 3D representation of urban environment consisting of urban forms and objects such as buildings and also other infrastructure, vegetation, land and water. This is consistent with the existing description by researchers [22, 39-41]. 3D city models are developed by means of different data acquisition techniques. As also noted by Biljecki et al [18], data acquisition techniques for 3D city models range from photogrammetry and laser scanning, extrusion from 2D prints, synthetic aperture radar, architectural models and drawings, hand held devices, procedural modelling and volunteered geo-information. Applications of 3D city models now extend beyond visualisation to analysis and planning in various domains (mobile telecommunication, disaster management etc.) connected to the built environment [42].

There have been speculations of promising developments in improving 3D city modelling with the emergence of new technologies such as the incorporation of semantic information and the implementation of the standards for Web 3D Service (W3DS) and the Web View Service (WVS), approved by the

Open Geospatial Consortium (OGC) [20, 43]. Such improvements efforts are already evident in the report by Falquet et al., [44] which identified three categories of city models: (i) City/urban model (ii) 3D city/urban model and (iii) Semantic 3D city model. A city model/urban model is a representation of a part of the real world encompassing (the locations of) urban entities and the global urban environment. 3D city/urban model is a model representation of the urban environment in a 3-dimensional geometry (see Fig. 2). Whereas a semantic 3D city model entails a 3D city model that additionally has urban knowledge or semantic information attached to it. Semantic 3D city models are integrated with attributes of objects (nature, usage, etc.), and can also contain relationships between these objects (topological, spatial, etc.). Such models can undergo semantic enrichment by adding entities and elements of intelligence to enhance connections to the real world which can become foundations for future smart cities [44].

Fig. 2. Holistic City CityCAD

V. Discussion

A classification of the commonly existing BEIM tools is given in Table 1. The table provides information on some key BIM, and CEIM, and CIM systems. A more comprehensive list and classification of exiting BIM tools have been covered in Abanda et al [8]. For CIM tools, the Autodesk LandXlporer is of interest. The components of the LandXplorer system include 3D Authoring System, 3D Geo-Database System, 3D Editor System, 3D Presentation System and Geospatial Digital Rights Management System. These components provide the LandXplorer system with five different groups of functional capabilities. These are (i) editing tools for the manipulation of 2D vector graphics and 3D graphics objects including ability to manage LoD-1 to LoD-4, (ii) navigation tools such as metaphor based controls including virtual helicopter, airplane, and pedestrian panning and zooming gaming controls (iii) animation tools for animation sequencing design and recording within the virtual 3D city model, (iv) printing tools for high resolution poster printing and generating virtual panorama images and movies and (v) import and Export tools used for processing exchanging 2D raster and vector data, GIS computer graphics, CityGML, 3DS, VRML and X3D. LandXplorer was initially owned by the German company 3D Geo (affiliated to Hasso-Plattner Institute) [22] and has now been acquired by Autodesk with the potential of becoming a mega-platform to link a single building information model on a large scale as part of semantic 3D city model [45]. The new version of the Autodesk LandXplorer claim to be able to aggregate geospatial information mapping (GIS), civil engineering, CAD, BIM, and utility network detail in a single city model [46].

VI. Conclusion

The advances in IT now allow the increasingly close representation of real life physical elements with their digitized counterpart (in the form of objects governed by rules). BIM concerns the designing of building structures based on a local coordinate systems. A group of applications, termed CEIM, also exist for modelling information on civil engineering infrastructure. CIM systems, on another hand, cover geographic elements and use the earth coordinate system to capture urban forms. Existing applications of CIM vary in the size of spatial area they can accommodate and in functionalities. Thus, information modelling systems in the built environment have their individual strengths which can be harnessed for the reason of integration for better collaboration. The integration of systems in the built environment has been suggested as vital to improving efficiency and productivity and therefore constitutes an important area of focus for future directions of research. As such, this review presented record of systems in the built environment with clear definitions of their functions. This helps in clearing up confusion on existing systems and areas of overlap to stakeholders in the built environment. We conclude that stakeholders should give strong consideration to interoperability needs along the supply chain in which they work when obtaining information modelling and design systems in the built environment.

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TABLE I. BEIM SOFTWARE PRODUCTS

Product	Description	Exchange file types and integration	Web page
	Building Information Modelling software products		
ArchiCAD	This is mainly AIM system that allows architects to freely explore design ideas and carry out precise documentation and high quality productions.	IFC, IFCXML, .IFCZIP, DXF, DWG	http://www.graphisoft.com/archicad/
Revit	This is currently a building design suit which combines Architecture, Structures and Service in a single modelling environment.	DWG, DXF, RVT, IFC, gbXML	http://www.autodesk.co.uk/products/revit-family/overview
Vectorworks Architecture (Nemetschek)	This software allows design in 2d and 3D with application of free-form surface and solids modelling tools.	DXF, DWG, IFC	http://www.vectorworks.net/architect/
SolidWorks	It provides solutions that cover product development process including workflow-design, verification, sustainable design, communication and data management.	DXF/ DWG, IFC, 3DS	http://www.solidworks.co.uk/
MicroStation	It is used for 2D and 3D CAD and for information modelling regarding architecture, engineering, construction, and facility operation. It is also equipped with design applications for roads and rail, bridges, buildings, communications networks, water and wastewater networks, process plants and mining	DXF, DWG, 3DS, IFC	https://www.bentley.com/en/products/brands/microstation

	Civil Engineering Information Modelling software products		
AutoCAD Civil 3D	A software package for civil design and solution documentation of infrastructure modelling regarding project performance, maintain more consistent data and processes and respond faster to change.	DXF, DWG, LandXML, DGN	http://www.autodesk.co.uk/products/autocad-civil-3d/overview
Infrastructure Design Suite	An autodesk family civil engineering package that combines tools for planning, design, building and managing civil and infrastructure utilities.	DXF, DWG, LandXML, DGN	http://www.autodesk.com/suites/infrastructure-design-suite/overview
Tekla Civil	This is used by professionals for product modelling and the comprehensive editing and management of infrastructure data	DWG, DXF, DGN, LandXML	http://www.tekla.com/products/tekla-civil
GEOPAK Civil Engineering Suite	An all in one civil engineering design application for 3D modelling, construction-driven engineering and analysis with opportunity to streamline workflows and perform design visualization in real time.	DXF, DWG, 3DS, IFC	https://www.bentley.com/en/products/product-line/civil-design-software/geopak-civil-engineering-suite
	City Information Modelling software products		
Autodesk LandXplorer Products	This urban design products help to create, manage, and distribute digital city models-promoting the sharing of information about urban change with project stakeholders. It combines CAD, BIM, geospatial, civil engineering, and infrastructure data into a digital city model	DEM, JPG2K, DTED, MrSID, ECW, PNG, ESRI Grid, TIFF, JPEG, ESRI ASCII, NITF, Works with 3DS, FBX, GML, SHP, STL, and XML Data	http://usa.autodesk.com/adsk/servlet/pc/item?siteID=123112&id=15005087
ESRI ArchGIS for Desktop	Create, analyze, store, and share geographic geospatial information and build maps with up-to-date data, combined with deep information analysis.	DWF, DXF, DWG, CityGML and XML, IFC 3DS, DWF, DXF, DWG, CityGML	http://www.esri.com/software/arcgis/arcgis-for-desktop
FME	Extract data from many BIM systems and convert them into different formats for other purposes	Supports BIM formats including those of Autodesk Revit, Trimble SketchUp and IFC	http://www.safe.com/fme/
Bentley Map	Is an engineering-accurate, 2D/3D desktop GIS that provides infrastructure professionals with geospatial tools to create, maintain, analyse and share spatial information.	IFC	https://www.bentley.com/en/products/product-line/asset-performance/bentley-map
CityCAD	It is a new urban early design software tool for conceptual 3D masterplanning of sites from 1 hectare up to about 200 hectares in size. Covers the sketching of street layout including buildings, block densities manipulations	2D or 3D DXF (CAD), Excel	http://www.holisticcity.co.uk/index.php/about-citycad
ESRI CityEngine	A tool for improved urban planning, architecture, and design. It uses 3D visualization power to explore relationships of projects, assess their feasibility, and plan their implementation	KML, WCS, WFS, WMS, WMTS, WPS, KML, GeoRSS, CSV, TXT, and GPX, GeoJSON, KML, CSV, GeoPackage, GDAL, MBTiles, WKT, and WKID.	http://www.esri.com/software/cityengine/
LuxCarta 3D City Models	This tool is used for producing 3D city models at various levels of detail of real-world, fully interactive, geographically accurate models of entire cities. These city models can be deployed in various applications such as navigation and location-based services, game environments, military and security, and news graphics.	*Not indicated*	http://www.luxcarta.com/products/3Dcitymodels.htm
Galantis 3D City micro planning model.	This tool provides data on all above-ground features and city infrastructure such as buildings, bridges, vegetation. 3D City Models are extra-accurate high resolution geodata for networks (3G,4G, GSM, LTE, WiMax, UMTS, CDMA and HSDPA) micro-planning and optimization in densely built-up areas	Aircom Asset, ATDI ICS Telecom, AWSP CelPlan, EDX, Forsk Atoll, Mentum Planet AWE WinProp, CRC-Predict, Orange Labs Model, Pace 4G, Wavecall WaveSight	http://www.galantis.com/maps/3d-city-models
3D Labz's	3D Labz's 3D digital models enable designers and planners to study the impact of urban development planned and the effects and problems of proposed development activities that is to happen at any particular site	*Not indicated*	http://3dlabz.com/3d-digital-city.htm