A Literature Review on BIM for Cities Distributed Renewable and Interactive Energy Systems

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Abstract

The havoc caused by COVID-19 has further strengthen the case for greening cities and ensuring a quicker economic recovery much desired by various governments. To this end, the appetite for Distributed Renewable and Interactive Energy Systems (DRIES) as a preferred option to retrofit cities has grown amongst policy makers. However, DRIE sources are complex and disparatepresenting challenges integrating into a unified system for urban retrofitting. Yet, integrating Building Information Modelling (BIM) and DRIES provide possibilities of effective assessment. Research of BIM applications at a city level is still very sketchy talk less in the domain of DRIES. This study investigates the opportunities and barriers of the application of BIM for the performance assessment of DRIES in the context of the transforming our environments into low carbon cities.A systematic literature review and case study review were used to achieve the aim of this study.

Key words: BIM, Distributed Renewable Energy Systems, Environmental impacts, Retrofit, Urban energy

1. Background

The COVID-19 pandemic has had a devastating impact on the economy of many countries. In response to the growing spread of the virus globally, many governments have implemented nation-wide lockdowns in late March 2020. The lockdowns are beginning to be eased but the impact of the pandemic on most economies is likely to remain deep and long-lasting. To stimulate their economies, many countries are beginning to elaborate on post-COVID recovery plans. Due to the severity of the crisis in which COVID-19 has plunged the world, embracing a green approach to relaunching the economies is becoming the least of priorities of many countries (Schwarze, 2020). This reluctance is in spite of the reported benefits of rolling out green strategies as a main pillar of development for cities. Previous studies have revealed the immense benefits of retrofitting cities as a main driver for economic development as well as improving the environmental sustainability of cities (Keivani et al., 2010). Other recent studies have identified retrofitting cities as one of the 7 key areas for relaunching economies as part of the wider global recovery plans during and post COVID-19 (Gulati et al., 2020; UN-Habitat, 2020).

However, most studies have often focused on single buildings with little emphasis on city scale projects delivered using an integrated approach. Shen and Sun (2016) proved thatintegrated design approach can achieve significant system size reductions and large initial cost savingsas compared with the conventional separated design. The initial costs of the air-conditioning, photovoltaic andwind turbine systems can be reduced by 14.4%, 13.7% and 11.8% respectively (Shen and Sun, 2016) if an integrated approach is adopted in comparison to the conventional isolated one . The integrated designalso achieves improved grid friendliness and equivalently good indoor thermal comfort in comparisonwith the conventional separated design. Emerging BIM can be used to deliver integrated projects with other benefits such as achieving sustainability or green retrofitting requirements for cities. One such important sustainability requirements is the achievement Net Zero Energy Building (NZEB) standard. Modelling cities for NZEB compliance requires understanding key concepts such as key sustainability performance and measures for retrofitting cities. However, the lines between these concepts are often blurred especially its applications in a cluster of buildings at city level compared to isolated buildings. Furthermore, since the proclamation of the concept of Sustainable Development in the Brundtland report in 1987, it has been used as a buzzword directly or indirectly in scientific literature and also as a way to booster chances of acquiring funding for research grants. As such the use of sustainability, sustainable development, green development has been used in such a way that the proposed objectives usually falls short of expected outcomes in many peer-reviewed literature or research.This has implication on many concepts in the domain of retrofitting. Hence, this study will adopt a systematic literature review supported by case studies to explore the key concepts of retrofitting cities with the ultimate goal of identifying the role of BIM in modelling such concepts in facilitating the retrofittingof citiesthrough DRIES.

To facilitate understanding the remainder of this paper is divided into 6 sections. Section 2 dwells on DRIES. In section 3, NZEB in the context of District retrofitting is examined. Building on this, BIM for DRIES is covered in section 4. The method adopted for this study is presented in section 5. In section 6, the findings of this study are presented. The study concludes by a way of summary in section 7

2. Distributed Renewable and Interactive Energy Systems (DRIES)

2.1 Context

Globally, and in particular in Europe, research on low carbon transition is of central interest (European Commission 2011; European Commision 2014; European Commission 2018). Integration of knowledge and methodologies is one of the principal strategy that is expected to promote the future energy systems (Sovacool et al. 2015; Ernst, Fischer-Hotzel, and Schumann 2017; Hewitt et al. 2017) and accelerate the path towardszero-carbon solutions (Rogge and Johnstone 2017; Rogge and Reichardt 2016).

In recent years, the renewable energy sources have emerged as a valid alternative to develop innovative energy infrastructures for a low carbon environment and society (Baños et al. 2011). These infrastructures are expected to be represented by small units directly connected with the place of consumption and assembled in a sequence of nodes in order to organise a micro-energy network (Ackermann, Andersson, and Söder 2001).

The system interactivity is the specific property that must involve all components of the energy system (Bibri and Krogstie 2017) and enable the diffusion by computer devices and software. On the other hand, the concept of *smart-grid* is a fundamental part of the evolution of the energy systems (Soshinskaya et al. 2014) whose properties should be able to connect their flux to the local context specificity.

Many studies have considered the importance of interactivity to optimise the integration of knowledge and information technologies (Dimeas and Hatziargyriou 2007; Siano 2014) in order to improve the qualities of the environment (De Jong et al. 2015). Several studies have focused on the regulation of new forms of energy market (Catulli and Fryer 2012) while others on the users' role in supply and demand management (Goulden et al. 2014). Recent studies have highlighted the potential impact of the new generation of energy systems on the environmental qualities of the urban patterns, in which each component is likely to become a node of the network (Caird and Hallett 2018; Sibilla and Kurul, 2020). In this regard, an active building (i.e. building as a component of a distributed, renewable and interactive system) is emerging as a new concept. However, few studies move towards radical innovative concept of active buildings. For example, Aurich et al. (2006) pointed out how interrelations between physical products and non-physical services need to be considered proactively. Similarly, Azcárate-Aguerre et al. (2018) analysed the use of tangible products such as building technologies, with intangible maintenance and monitoring services. In detail, this study explored the application of Product-Service Systems organization principles in the delivery of Façades-as-a-Service. Nevertheless, focusing on a single building or individual component, these studies neglected the infrastructural vision.These studies have contributed to widen the vision of a possible new energy infrastructure system and define several aspects of the DRIES characteristics; however, the dimensional and localisation logics managed through DRIES demand further developments.

2.2 Overview of Distributed Renewable & Interactive Energy Systems

In this section, an overview of the main technologies associated with DRIES-based applications and their implications on the sustainable organisation of the built environment is provided. Firstly, a summary focused on the primary relationships between renewable technologies and local resources is given. Then, how these technologies can be integrated in order to organise a reliable alternative energy infrastructure is presented trough real case studies. Table 1 provides the main features concerning the following technologies: solar energy; wind energy; hydro and bio-energy. This is not a complete list, but it includes the main typologies of renewable energy systems, which can produce significant impacts on the physical configuration of buildings and settlements.

Table 1: Main features of renewable energy technologies in an urban or district context

Renewable technology	Cyclical time variation	Main parameters	Main area of application	Typology	Comment
PV Solar Energy	Hours (direct sunshine) Day (diffuse sunshine)	Solar beam irradiance. Angle of beam from vertical (Direct). Cloud cover Air Pollution (Diffuse).	PV- stand alone	Urban and rural	Performance is dependent of sunshine level and local weather conditions Storage/back-up usually required due to fluctuating
			PV- grid connected	Mostly Urban	
Wind	Minute to Hours (windfarm)	Wind speed. Height nacelle above ground.	Wind turbines - stand-alone - grid connected	Mostly rural	High fluctuating. Site-specific technology (requires a suitable site) Variable power produced therefore storage/back up required.
			Micro-turbines - stand-alone - grid connected	Urban and rural	
Bio-Energy (Solid Biomass and Biogas)	Year	Soil condition. Water. Plant species. Wastes.	Solid	Mostly rural	Vary many variation, connected to agriculture and forestry
			Liquid	Urban and rural	
Hydropower	Seasons	Reservoir height. Water volume flow.	Micro-Hydropower (5kW -100kW)	Mostly rural	Very site-specific technology (requires a suitable site relatively close to the location where the new power is needed) Droughts and changes in local water and land use can affect power output
			Mini-hydro (100kW-1MW)		
			Small hydro (1MW-20MW)		

Source, Adapted from: (UNDP, 2000, Hussain et al 2017)

Until recently, one of the most critical problems in organising an energy network composed of multi renewable technologies has been related to the different cyclical time variations, which characterises each of them. Currently, the interactivity of distributed systems is the property by which this deficiency can be resolved. Consequently, an increasing number of applications has been based on a new generation of interactive energy management systems (Sibilla, 2014). Table 2 shows an overview of a selection of ten embryonic applications of DRIES across Europe.

Table 2. Overview of embryonic DRIES applications

	Achievements				Technologies					
Context	**Number of Inhabitants involved**	**Geographical Area (m2)**	**% Energy Saving by Retrofit**	**% Energy production by FER**	**PV Solar Energy**	**Wind and Micro-wind turbines**	**Bio-Energy-Biomass**	**Micro-Hydropower**	**Biogas (Waste recycled)**	**Interactive Energy Management System**
Bracknell (UK)	52 000	27 500	30	40	X	X	X			X
Cerdanyola (SP)	10 000	3 400 000	55	33			X		X	X
Falkkenberg (SE)	20 551	240 000 000	24.3	65		X	X		X	X
Grenoble (FR)	26 000	2 100 000 000	41	21	X		X	X		X
London (UK)	10 000	710 000	10	62	X	X			X	X
Lyon (FR)	4 000	53 000	40	60	X		X			X
Ostfildern (DE)	10 000	1 500 000	30	80	X		X	X		X
Tudela (SP)	2 500	300 000	75	100	X	X				X
Växjö (SE)	2 500	2 000 000	31	95			X		X	X
Weiz Gleisdorf (AT)	14 000	30 000	23.9	30	X		X			X

Source: Adapted from EU(2014)

These projects in Table 2are outputs from the Concerto Programme, which is a European Commission initiative within the European Research Framework Programme (FP6 and FP7). They show that optimising the entire community's construction sector is more efficient than the individual optimization of each building. These case studies have played a pivotal role in affirming decentralized energy technology based on renewable systems and interactive management as a common practice to achieve NZEB target. Specifically, they have planned strategies tooperationalise the highest level of technology diversity.Such diversity should allow local communities to increase both their resilience and energy independence. In addition, the synchronization among these sustainable technologies can support decision-makers in re-writing the rules for organizing the territory, promoting new job opportunities, industrial challenges, environmental awareness and social participation. However, exploiting DRIES emerging properties as an innovative socio-technical apparatus to guide towards a low carbon society is an open issue. At the beginning of the new European Research Framework Programme (i.e. Horizon Europe), new advanced intelligent systems are now available. Thus, exchanging energy *in situ* is going to play a key role in meeting the EU's energy policy long-term targets for 2050. In this scenario, DRIES can be offered as a characterisation of the new paradigm of Positive Energy Districts (EU, 2020).

2.3 Specific challenges faced by DRIES

There are several socio-technical open issues, which are related to the scenario based on small-scale infrastructures such as DRIES.

First, it is clear the importance of the local dimension (Goldthau, 2014) and the specificities of each territory (Brandoni and Polonara, 2012); notwithstanding an operative framework at the local level remains unresolved. Second, as stated by several authors (Rogers et al. 2008; Wirth, 2014) when consumers have more control, tend to self-organise and co-operate to form community energy systems but, how the various roles of the actors (i.e. citizens, professionals, intermediaries and institutions) are connected in networks and how networks challenge the existing energy system is not clear. Third, as underlined by Walker (2008) the local energy initiatives could often be inhibited by technical barriers such as the lack of equipment, technical knowledge and expertise. A specific technical apparatus able to solve energy and environmental issues of DRIES has not been developed yet. Fourth, a substantial literature considers the socio-cultural aspects of the energy future (Miller et al. 2015; Weimer-Jehle et al. 2016); but how to organise a DRIES at local level remains a challenge. Fifth, nowadays the experiments at local level tend to relegate the interactivity of the new energy systems to smart meter applications (i.e., to control supply and/or demand-side of the energy production) (Maroufmashat et al. 2015) while the most important implications of DRIES in re-configuring the environmental and spatial qualities of settlements remain confined to sectorial studies.

At the present one of the main obstacles to the advancement of DRIES in Low Carbon Transition is the absence of a systematic approach and the lack of appropriate tools. Indeed, this study is based on the assumption that the energy transition is not only an opportunity to reduce the energy impact of our settlements and create a new energy market, but it is an opportunity to achieve the following objectives:

- enhance the local geographical condition (e.g. access to solar) related to urban transformation processes;
- to deliver a new generation of buildings, which act as nodes of the future energy network;
- to elaborate an advanced procedure to manage the environmental impact of this new form of infrastructure in the course of the time.

The starting point of this exploratory research is a preliminary procedure, which was developed in a prior study (Sibilla and Kurul, 2020) where some DRIEs features were established in order to classify potential active, neutral and passive nodes of the energy net respect to specific urban regions. Although this prior study introduced a large-scale investigation, contrasting approaches focused on single buildings, some issues were neglected.

Firstly, the preliminary procedure did not consider the energy performance of the buildings' envelop, focusing only on their urban context condition related to the solar access. Secondly, neglecting the energy performance of the buildings' envelop, it also bypassed the environmental impact and the cost/benefit analysis related to the process of transformation of buildings from the current situation to passive and active node of the grid. Therefore, exploring the potential of BIM in mondelling performance data within the context of a DRIES is a possible solution in order to fill this gap. The hypothesis is that such integrationenables to manage the urban decision-making processes of DRIES organization, which involve: the morphological rebalance of buildings and urban spaces to improve exposure to renewable energy resources; the definition of rules and parameters of environmental regenerations strategies integrated with the DRIES vision that can be implemented in the short, medium and long term; thescheduling of a set of urban and architectural design transformations to reconcile the energy supply and demand characteristics of active, neutral and passive nodes.

3. NZEB in DistrictRetrofitting

The term net-zero energy building (NZEB) has so many synonyms. These include: nearly zero energy building (NZEB), zero-energy building (ZE), zero net energy (ZNE) building, and net zero building (NZB). According to article 2 of the EU Directive on the energy performance of buildings adopted in 2020, a nearly zero-energy as '…a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby'.

As can be noted from these definitions the concepts implies that the transformation should lead to a high energy efficient buildings and the minute energy left should be provided from a renewable source or a combination sources. Thus, no wonder the concept of near zero has received criticism amongst members of the public. Recently Greta Thunberg, one of the most popular teenage climate change campaigner argued for the term to be "real" zero not near zero (BBC, 2020). Shnapp et al. (2020) even goes further to request of "positive" energy districts, to mean zero-net energy is not enough and that buildings and districts should be able to produce more energy than it can consume.

Transforming or improving any asset to achieve a certain desired level of performance, e.g., NZEB or "real" zero, talk less of "positive" energy requires an in-depth understanding of the different activities to be undertaken. Broadly speaking, in the literature deep and conventional energy retrofit are the two most common form of energy related improvement (Zhai et al., 2011). Although there is no exact definition for a deep energy retrofit, it can be defined as a whole-building analysis and construction process that aims at achieving on-site energy use minimization in a building by 50% or more compared to the baseline energy use (calculated using utility bills analysis) making use of existing technologies, materials and construction practices (Less et al., undated). Conventional energy retrofits focus on isolated system upgrades (i.e. lighting and HVAC equipment). These retrofits are generally simple and fast, but they often miss opportunity for saving more energy cost-effectively (Zhai et al., 2011).

4. BIM for DRIES

Recent interest in BIM and its applications has equally seen an avalanche of publications highlighting various definitions. Our previous works (Abanda et al., 2015) have critically appraised some of these definitions, hence these works will not be duplicated in this study. However, it is important to highlight that of the numerous definitions, that of theUK Construction Industry Council (UK CIC) is more encompassing and defines BIM as … “an innovative and collaborative way of working that is underpinned by digital technologies which support more efficient methods of designing, creating and maintaining the built environment”.The UK CIC’s definitions is in alignment with the joint proposed definition of the UK construction industry by RIBA, Construction Project Information Committee (CPIC) and buildingSmart – leading authorities in the field.

Encapsulated in the aforementioned definition are three main concepts: model, process and technology or software. Bazjanac (2004) elaborated on this by defining the model (often called a Building Information Model (BIM)) as an instance of a populateddata model of buildings that contains multi-disciplinary data specificto a particular building, which they describe unambiguously. Furthermore, from a process perspective, the author views Building Information Modelling (BIM) as a verb is to mean the act or process of creatinga Building Information Model (BIM-the-noun). The process aspect is widely argued to be the underpinning principle of BIM (Eastman et al., 2011; Lee et al., 2006).Retrofitting a community to meet any sustainable performance standard such as NZEB requires a detailed understanding of its individual constituents. Four main components should be considered when designing out or retrofitting for NZEB compliance.

Buildings: Buildings are the main elements of communities or cities. They are many and consist of heterogeneous structures, heating systems, occupancy behaviour, etc. They therefore present two main challenges. First, it is a huge challenge modelling a large number of sub-components, then integrating to form a final model or system. Secondly, scalability becomes an issue as it becomes quite difficult to simulate a significant number of buildings. Due to the complexity and scalability issues related to modelling buildings at community level, researchers have proposed the use of simplified building models for simulation and optimization of district energy systems, as they can significantly reduce the computation time (Kim et al., 2014;).

Renewable energy systems: For effective integration of renewable energy systems with BIM, they should be modelled in a BIM systems. Once modelled, it can easily be embedded in building models during design or out of the building as part of a stand-alone energy system. An example of the former includes solar panels that can be designed an included in BIM object library and simply re-used during the design of a building. For the later, a whole photovoltaic system can be modelled in a BIM software and erected in a yard to power a nearby building.

Grid energy system, electrical and thermal energy network: For effective supply of services, an optimal network needs to link the different elements of the community. The BIM systems provide the possibility to simulate the different networks. The networks consist of terminals (nodes) and arcs with links the former. Nodes could be buildings and photovoltaic systems. On the other hand, an arc could be a cable linking the stand-alone photovoltaic system and a building.

Data Modelling: The element should be enriched with data for different applications. This is an important aspect of BIM. Depending on the use or applications of each element in the community. As argued by Eastman et al. (2011) building components that are represented with intelligent digital representationsand can be associated with computable attributes and parametric. The componentsshould include data that describe how they behave, should be consistent and contain non-redundant data.

5. Research Method

As discussed in the background section the domain of sustainability has received significant interest in recent years. This interest has led to the concept being used interchangeably and most of the times as buzzwords to achieve certain objectives. In fact, Károly (2011) argued the concept has been abused. Thus, not surprising most research databases have huge amount of literature about the concept of sustainability. Therefore, a systematic literature review offers an unbiased and logical approach to investigate studies in the area of DRIES. Given that most of the studies in the literature are mostly on single buildings, an analysis of case study projects at city level is undertaken to validate the outcome of the literature. Specifically the 3 steps of the methods used are: identification of relevant literature, content analysis, and validation of studies.This is captured in Figure 1.

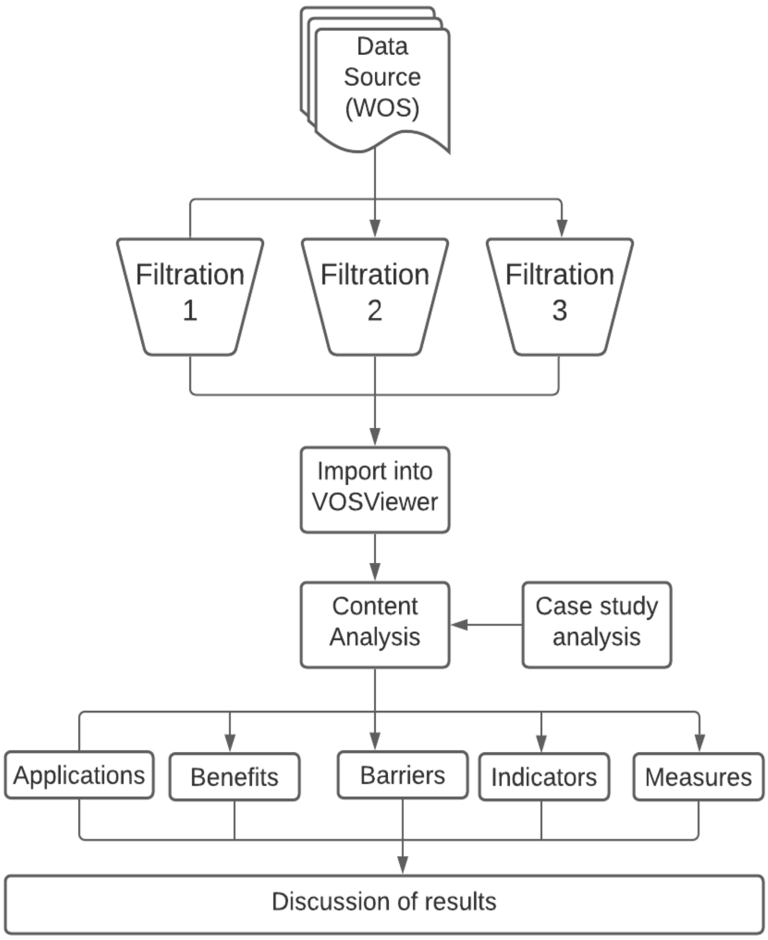

Figure 1: Research design

Sourcing the literature from Web of Science database: In this step, a systematic approach to identity the different literature sources is conducted. The Web of Science database is adopted as it is one of the leading sources for research outputs. Given the crosscutting nature of this research involving BIM, renewable energy, cities, distributed networks; it was impossible to choose a single search term that will lead to an output that will cover all these areas. Consequently, a list of terms were selected that cover various aspects of the domain was developed and used in the search. This is presented in the first column of Table 3.

Table 3: Method search terms

Search terms	1st Outcome	Filtration		
		1st	2nd	3rd
"District energy*"	403	237	213	502
"Urban energy*"	1273	846	446	
"Smart cities" AND "Renewable*"	241	105	60	
"Information modelling" AND "energy*"	275	141	105	450
"City information " AND "energy*"	8	5	5	
"Building information " AND "energy*"	859	473	324	
"City information " AND "retrofit*"	1	1	1	
"Building information " AND "retrofit*"	101	64	43	

When the search terms are introduced and conducted, the output are displayed in the second column of Table 3. The search criteria is then restricted to only journal articles which leads to a reduction from the initial output and then presented in column 3. Secondly, a broad-brush approach was used to check the relevance of the articles. This led to the elimination of articles that had nothing to do with BIM/CIM for district level retrofitting and the output presented 4th column of Table 3. Examples include heat combustion systems in engine vehicles (Wu, 2019) and heat storage system with various diameters of aluminium tubes (He et al., 2019) which have nothing to do with cities. Lastly, duplicates were eliminated and the final number of articles is presented in the last column of Table 3. In order to easily identify the duplicates, the first 3 rows of Table 3 were analysed together because they did not have anything related to information modelling and the last 5 rows were analysis together as the had the word information modelling in each of them. The analysis of this study is based on (450+502=952) articles stated in the last column of Table 3. These articles were imported in VOSviewer (https://www.vosviewer.com/) where their scientific landscape was explored and the results presented in section 6.1.

Content analysis: In research, content analysis can take on a quantitative and/or qualitative approach, applied either inductively or deductively depending on the specific research questions and research design (Elo and Kyngäs, 2008). Due to the specialist and crosscutting nature of this research, a qualitative approach was adopted. This qualitative approach involves interpreting the manifest and latent content of the text, facilitating, through rigorous analyses, an understanding of a phenomenon's critical processes, motives and objectives, while deriving rich meanings and insights from the text (Elo and Kyngäs, 2008; Duriau et al., 2007). The content analysis of the selected literature led to the identification of data/information that can broadly be categorised into BIM application in DRIES, benefits of BIM for DRIES, barriers to BIM applications in DRIES, performance indicators for DRIES and urban retrofitting options.

Case study review: The content of some exemplary projects were analysed to establish the kind of performance indicators used and retrofiring strategies adopted. The projects included the Scottish Retrofitting programme (http://www.retrofitscotland.org/) and the European Union Build Up retrofitting programmes (https://www.buildup.eu/en/practices). The outcomes which include a list of indicators and urban retrofitting options were used to validate those from peer-reviewed articles described in the preceding step.

6. Findings and discussions

6.1. Main Sources and Preliminary findings

“City information ” AND “energy*” versus “building information ” AND “energy*”: The former yields 8 compared to 859 for the latter. This is consistent with the literature that most information modelling research focus on single buildings with very few on clusters of buildings.

"City information " AND "retrofit*" versus "building information " AND "retrofit*" : Similar to the preceding finding, the search research for the former yielded 1 compared to 101 for the latter. It can also be concluded that 101 is at least 8 times less than 859 suggesting that most BIM/CIM application research seldom focus of retrofitting.

To gain a scientific landscape of the articles, the filtered total of 952 was imported into VOSviewer and word clouds generated about the sources of the articles (Figure 2) and country of their publications (Figure 3).

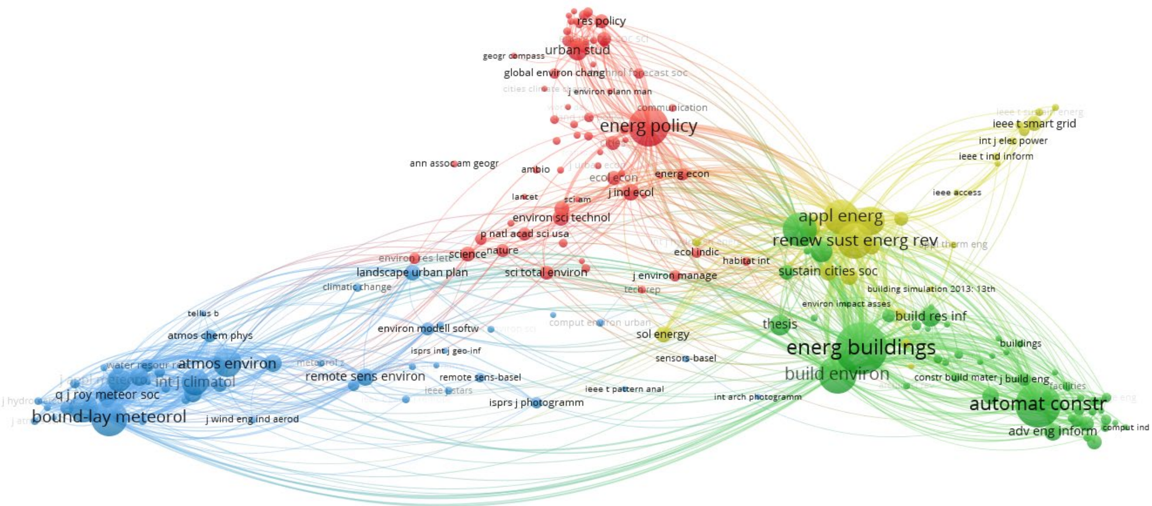

Figure 2: Word cloud of publication sources

Figure 2 suggest most of the articles are published in appropriate journals with Energy and Buildings, Energy Policy, Automation in Construction and Renewable & Sustainable Energy Reviews standing out.

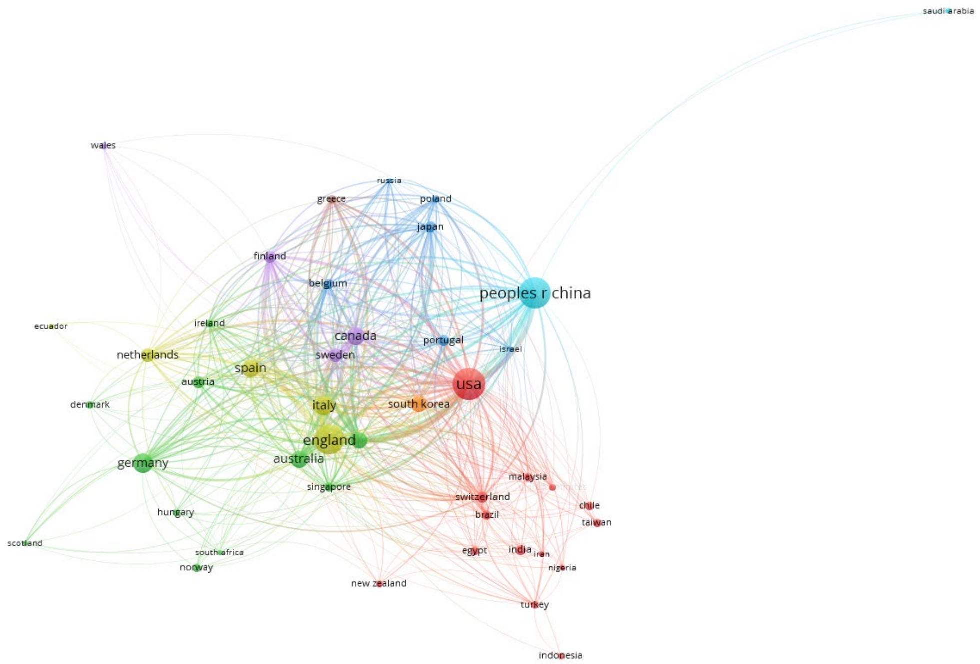

Figure 3: Word cloud of country of published articles.

As can be seen from Figure 3, most of the publications are from the developed countries with the USA taking the lead. Published articles from developing countries especially from Africa are missing.

6.2. BIM applications in DRIES

Development and data extraction: Sporr et al. (2020) proposed an IFC-based BIM data method for the automated development of a general-purpose building energy provisioning and distribution system. The approach can facilitate the extraction of hydraulic structure of the energy system and derive a control strategy from it.

Design of components: A study by Piselli et al. (2020) developed an integrated HBIM Simulation Approach for Energy Retrofit of Historical Buildings. The system was implemented on a case study of a Medieval Fortress in Italy. In the study, architectural model of the case study building was developed in Revit- one of the leading BIM design authoring tool. Specifically the components designed include column, pavilion roof, roof clay bent tiles and tiles, barrel vault; ancient wooden door, wooden frame with beams and joists for roof and floor.

Energy simulation: Chen (2019) demonstrated procedural steps in the application of green BIM and analyzed restrictions on the implementation of green BIM to the analysis of NZEB design. The main software used were Revit and Green Building Studio (GBS). The Autodesk Revit platform relies on Autodesk's cloud GBS to transmit information created or input on the Revit platform, including (1) building geometric information (configuration, shape, and orientation), (2) geographic and weather data (geographic coordinates, environmental characteristics, temperature, humidity, path of the sun, and wind rose, etc.), and (3) non-geometric attributes and parameters (spatial categories, wall structures, thermal conduction performance, active equipment options, operating plans, and parameter settings), in the gbXML format to GBS' DOE-2 energy simulation engine in the cloud. Similarly, Abanda and Byers (2016) used Revit and GBS to investigate the impact of building orientation on energy consumption of buildings. The authors used a single case study to implement their methodology.

Operation Maintenance and Flexibility: Energy management is a crucial issue that needs to be maintained under different operating conditions throughout a project's lifecycle (Al Ka'bi , 2020). Such 24/7 self-reporting capabilities of BIM-based facility management make energy monitoring very easy. Moreover, BIM also enables the flexibility to assess and reach to new energy targets during any type of revisions specially those made on functionality of the built environment (Bortoluzzi et al. 2019). Hence, any design changes either made on the BIM or energy analysis tool can easily be entertained in a simple iterative manner.

6.2 Benefits of BIM for DRIES

Holistic view: Using BIM to simulate a city provides a possibility to have a bird view of all the system interacting together. Such a bird view or holistic view can inform better decision-making. These impactful decisions bring high/optimal energy performances without compromising architectural and technical values of projects (Schlueter and Geyer, 2018). Furthermore, significant amount of potential cost and time reductions can be achieved (Gao et al. 2019).

Real-time analysis: By using BIM, first, it avoids generating error-prone models within energy analysis platforms (Andriamamonjy et al., 2019). All geometric information is prepared within the BIM environment and cleared off from any clashes between different disciplines. Second, it is also possible to integrate systems together and conduct real-time analysis of their performance. The improved integration/collaboration leads way for quick and better quality and precisions in design, facility management and feasibility analysis of projects.

Visualisation: As often said, a photo is worth 1000 words cannot be further from the truth about BIM for DRIES. Using BIM it is possible to visualise the different systems and how connected with each other.

6.3 Barriers of BIM for DRIES

Complexity: Each element in a city consist of other sub-components that are further characterised by properties that defines its existence and behaviour. For example, Egan (1998) stated that a typical house contains 40 000 components, compared to 3 000 parts for an average car. The properties of material (e.g., concrete) that make up this components and their interaction with each other further just shows how a functioning urban environment can be complex. This complexity present challenges with information modelling and understanding of the functioning of the urban environment.

Scalability: The sheer size of an urban environment including its numerous components presents challenges to making alterations if it is to be improved to achieve a desired level in a computer software. Furthermore, the computer power may be limited in processing data from a very complex urban model.

Interoperability between software systems: Issues with software interoperability in the BIM domain has been widely reported in the literature (Abanda et al., 2015:2017). For urban information processing to effective, the systems for management such information must be interoperable. Although standards such as IFC, gbXML and CityGML can ease interoperability, most software are limited in reading and generating such files. Utkucu and Sözer (2020) identified certain losses of data when exporting geometric models from a BIM environment to energy simulation platforms. For this reason, such deficiencies require adding all missing information manually to achieve the desired level of information need in the simulation output. Hence, it incurs unnecessary delays in the design process. On the other hand, despite the successful transfer of essential data from the BIM environment, there are cases on some energy simulation platforms where material types and properties are not retrieved/read (ibid). Such instances will also require a time-consuming redefinition of these data on the energy analysis tool itself.

Lack of standard components:BIM objects are a key to designing elements of any artefact in an urban environment. While standard objects have been developed for buildings, most other components of the urban environment still have a limited number of the same. For example, most BIM object library (e.g. BIMObject (https://www.bimobject.com/en/product)) have very few photovoltaic system components.

Performance indicators: To achieve NZEB standard at an urban level, clear indicators that are measurable must be set. Some sustainability factors are difficult to quantity; as such, their indicators can at times be difficult to measure. In addition, in some cases, data for some indicators have different units. For example, it is possible to have embodied energy intensity being measure in MJ/Kg and in certain cases in MJ/m^2. This disparity is often due to product suppliers preferring one mode or the other.

6.4 Performance indicators of DRIES

Designing out for NZEB compliance requires an in-depth understanding of the performance indicators (Table 4), the improvement measures (Table 5) and the elements required for the measures (Figure 5)

Table 4: Performance indicator DRIES

Performance indicators	Sub-indicators	Units	Scale	Sources
Environmental	Global Warming Potential (GWP) (Kg CO_2)	kg CO_2 eq/m^2/year	District	Inayat et al., 2020, Nikodinoska et al. 2018
	GWP investment	kg CO_2 eq/m^2		IEA (2017)
	GWP reduction	kg CO_2 eq/m^2	District	Manjarres et al. 2019, Sozer et al 2019
	Primary energy consumption	MJ/a·m^2	District	Happle et al., 2020, Suclu et al. 2019, Bunning et al. 2018
	Embodied energy of refurbishment scenarios	MJ/ m^2	District	Neroutsou et al., 2016, Lydon et al. 2017
	Embodied carbon	kg CO_2 eq/m^2/year	District	Zarrella et al., 2020, Pylsy et al., 2020
	Energy payback time	Years	District	Manjarres et al. 2019,
Economic	Operational energy cost	€/year , $/KWh, ($/KW and $/KWh)	District	Yang et al., 2020, Sozer et al 2019, Pylsy et al., 2020, Fanti et al. 2015
	Investments	€, €/m^2 of refurbished surface	District	Zarrella et al., 2020
	Life cycle cost	€, €/m^2 of refurbished surface	District	Happle et al., 2020, Neroutsou et al., 2016, Bartolozzi et al. 2017
	Return on investment	%	District	Happle et al., 2020
	Payback Period	Years	District	Calise et al. 2020 Wu et al., 2020, Sadi et al. 2020, IEA (2017
Social	Energy poverty measured as % of inhabitants that use more than 10% of their incomes to pay energy bills	%	District	IEA (2017)
	Jobs creation		District	Becchio et al., 2018

Energy	Energy demand	kWh/m^2	District	Yang et al., 2020, Kalaychioglu et al. 2017, Happle et al., 2020, Wu et al., 2020, Mitchell et al. 2020
	Final energy consumption	kWh/m^2	District	Henchoz et al. 2015, Yang et al., 2020, Bunning et al. 2018
	Peak load and profile of electricity demand	kW	District	Wang et al. 2020, Happle et al., 2020
	Peak load and profile of thermal energy demand	kW	District	Yang et al., 2020, Happle et al., 2020
	Degree of energetic self-supply	kWh/kWh	District	Wu et al., 2020
	Net fossil energy consumed	kWh/m^2		IEA (2017)
	Total energy use per capita	kWh/hab · year	District	IEA (2017)
	Total residential electrical energy use per capita	kWh/hab· year	District	IEA (2017)
	Energy demand covered by renewable sources	%	District	Happle et al., 2020, Ramachandra (2009)
	Total residential natural gas energy use per capita	kWh/hab· year	District	IEA (2017)
	Total residential butane gas energy use per capita	kWh/hab· year	District	IEA (2017)
	Energy consumption of public buildings per year	kWh/year·m^2 KWh/year	District	Happle et al., 2020
	Energy use from District Heating	kWh/year·m^2 , KWh/year	District	Yang et al., 2020, Tranet al. 2019, Pylsy et al., 2020, Happle et al., 2020
	Energy use from Biomass	kWh/year·m^2	District	Wu et al. 2020, Mendoza et al., 2018, Stephen et al. 2016
	Energy use from PV	kWh/year·m^2 , KWh/year	District	Tranet al. 2019, Happle et al., 2020, Boccalatte et al., 2020, Moran et al. 2014
	Energy use from Natural Gas	kWh/year·m^2	District	Mendoza et al., 2018,Al-Obaldli et al. 2020, Yang et al. 2020
	Energy use from Solar Thermal	kWh/year·m^2	District	Yang et al., 2020, Happle et al., 2020, Boccalatte et al., 2020, Sadi et al. 2020

	Energy use from Hydraulic	kWh/year·m^2	District	Van Der Heijde et al. 2017, Oppelt et al. 2016, Ayele et al. 2018
	Energy use from Geothermal	kWh/year·m^2	District	Achellas et al. 2020, Yang et al., 2020, Soltani et al. 2019, Bartolozzi et al. 2017
	Energy use from Mini-Eolica	kWh/year·m^2	District	
Comfort	Local thermal comfort	Level		Moreno-Rangel et al. 2020, Udrea et al., 2020, Echarri-Iribarren et al. 2019, Figueiredo et al. 2016, Fanti et al. 2015
	Local temperature deviation from set-point	Δ ºC	District	Happle et al., 2020, Udrea et al., 2020, Echarri-Iribarren et al. 2019, Bunning et al. 2018
	Percentage outside range	%, Δ (COM0I)xtime	District	Udrea et al., 2020, Echarri-Iribarren et al. 2019
	Indoor air quality		District	Becchio et al., 2018, Moreno-Rangel et al. 2020, Happle et al., 2020
	Visual comfort	Lux	District	IEA (2017)
Urban	Percentage of buildings compliant with EPBD standard	%	District	Gatt et al. 2020, Zarrella et al., 2020, Marzinger et al. 2020, Kalaychioglu et al. 2017
	Percentage of buildings compliant with EnerPhit standards	%	District	Neroutsou et al., 2016, Leardini and Manfredini (2015), Moran et al. 2014
	Percentage of buildings compliant with Passivhaus standards	%	District	Moreno-Rangel et al. 2020, Mitchell et al. 2020, Finegan et al. 2020, Udrea et al., 2020
	Percentage of buildings compliant with nZEB standards	%	District	Boccalatte et al., 2020, Van der Grijp et al., 2019, Mendoza et al., 2018, Becchio et al., 2018, Gatt et al. 2020
Global	kwh energy saved / euro invested	kWh/y / €	District	Happle et al., 2020, Zarrella et al., 2020, Wu et al., 2020, Van der Grijp et al., 2019, Bunning et al. 2018
	CO2 saved / euro invested	Kg CO_2/y / €	District	Zarrella et al., 2020, Pylsy et al., 2020, Wu et al., 2020, Becchio et al., 2018, Marzinger et al. 2020

Table 5: Retrofit measures

Building element	Measure	Level	Source
Ground	Interior insulation	Single building	Streicher et al. (2020)
Roof	Exterior insulation	Single building	Streicher et al. (2020)
	The existing old pitched roof was removed and a new flat roof was installed with 35 – 40cm of polystyrene. U-value: 0.10 W/m^2K.	District	IEA (2017)
Ceiling	Insulation	Single building	Ahlrichs et al. (2020)
Wall	Exterior insulation	Single building	Streicher et al. (2020)
	The basement walls were insulated with 260 – 290 mm insulation on the outside.	District	IEA (2017)
Corridors	The new lighting system in the building is established as a completely new LED lighting system in corridors and offices.	District	IEA (2017)
Window	Triple glazed	Single building	Streicher et al. (2020), Ahlrichs et al. (2020)
	Passive house	Single building	Streicher et al. (2020), Ahlrichs et al. (2020)
	An external shading device is installed and integrated in the facade module. This external shading device helps to reduce the solar gains and therefore to avoid overheating of the rooms in the warm periods of the year.	District	IEA (2017)
	New windows and daylight-controlled LED lighting in offices contribute to better daylight conditions.	District	IEA (2017)
Photovoltaic system	Photovoltaic panels are installed on roof or on facades	District	IEA (2017)
Solar thermal system	Solar thermal system with a collector surface are mounted on facades	District	IEA (2017)
HVAC	New ventilation System	District	IEA (2017)

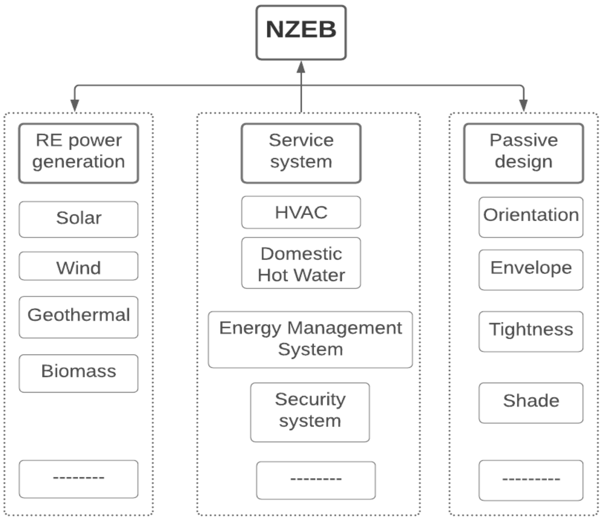

Figure 5: Design elements for NZEB (Adapted from Deng et al. (2014) and Table 5)

Figure 5 shows the key elements that should be considered when designing out for NZEB standard. Based on Table 5, most of the NZEB measures seldom dwell on passive principles. This is so despite the fact, passive design strategies are features innate to the form and design of a building that channelize available natural resources to ensure thermal comfort. In fact, sound passive design principles are the first stepping-stone on the path to zero energy buildings as studies have shown how their applications can sharply reduce energy use and only then use renewable energy systems to meet the residual energy needs.

7. Discussions

This study explored how BIM can be used in modelling Distributed Renewable and Interactive Energy Systems for improving the sustainability performance of cities. Achieving a NZEB standard is a minimum requirement for a high performant city. A recent report by the European Commission recommendation is even more stringent; it requires not just a NZEB but a net positive energy building standard (Shnapp et al., 2020). It is too hard to achieve his stringent requirement at a building level talk less of at a city level. This is due to the complexity of structures that make cities and the vast amount of data that they generate each second. In this paper an effort was directed to addressing some of the main concepts that should be considered in modelling cities in BIM for DRIES which include the main elements (section 4), the main performance indicators (Table 4) and some retrofitting measures (Table 5). While these main concepts can already serve as the bases for computing and assessing the sustainability performance of cities with the goal of achieving a net positive energy, a recent study by Sibilla and Kurul (2020) suggests it can even be more complex and challenging if other parameters such as homogeneity of urban units and buildings are taken into account. Homogeneous Urban Units are urban areas with similar characteristics, e.g. urban morphology while a homogeneous Building Group includes buildings with the same hourly energy demand profile. The challenge associated with achieving NZEB or net positive standard can attain unimaginable levels in cases where urban areas do not have similar characteristics and buildings have different energy demand profile. Although BIM has its own limitations, presently it is amongst the best and contemporary paradigm that can be used for exploring how to better integrate DRIES for aiding cities achieve its NZEB or net positive standard. Using BIM for DRIES can also aid in helping professionals design and/or retrofit cities to meet other sustainability goals especially if other emerging technologies can be considered and possibly integrated with BIM.

8. Conclusions

This study has revealed that DRIES is key to achieving NZED standards. The concepts uncovered are the applications of BIM for zero energy buildings, performance indicators, benefits and strategies to achieving NZED standard at district level. The challenges towards achieving NZED standards were also discussed. The findings can be grouped into 3 main categories. Firstly, most information modelling research focus on single buildings with very few on clusters of buildings. Secondly, studies about retrofitting at district level is not common compared to those at single buildings. Thirdly, BIM/CIM application research seldom focus of retrofitting with far too many on isolated buildings. Lastly, a major weakness is that the indicators, measures, and technologies are many leading to challenges in making informed decisions about how they could be used in achieving NZED standards in retrofitting projects. A key to overcoming this weakness is to develop a multi-criteria system that can aid in making effective decisions using the different concepts.

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