METHOD FOR 3D NEIGHBORHOOD MODEL CREATION IN CITYGML STANDARD AS BASIS FOR URBAN SIMULATION TOOLS

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ABSTRACT

Urban growth strains housing resources. Sustainable cities prioritize eco-friendly construction and resource efficiency. Norway has established itself as a leading country in sustainable construction. To address the mentioned challenges in Norway, it is necessary to analyze the local building stock in the first place, to gather information about the status-quo. Based on that, potentials for energy-efficient and sustainable renovation, redensification and the potential of new developments can be derived. To develop optimized strategies, buildings need to be assessed over their whole life cycle, using Life Cycle Assessment (LCA) methods. LCAs are primarily done at the building level, however, sustainable development strategies are needed on a larger building scale to accelerate the sustainable transformation.

As of now, the application of these concepts has resulted in endeavors to utilize contemporary technologies, such as employing 3D city models. While 3D modelling streamlines planning and decision-making, its adoption by planners is hindered by data integration complexities and the absence of an efficient building stock evaluation process.

This paper aims to promote spatial modelling for sustainable architecture, by creating a 3D model of Fredrikstad neighbourhood in Norway and conducting a housing stock assessment using computer-aided urban tools. The LCA process relies on 3D city models compliant with the CityGML standard, integrated into LCA software with Norway-specific data. The results will be analyzed in terms of operational energy demand, heat load and global warming potential. For the newly developed areas in the neighbourhood, the results will be compared against similar calculations processed by the syn.ikia project2.

The outcome of this study will be a comprehensive methodology for generating 3D models and assessing a case study based on these models. Notably, the paper does not delve into alternative scenarios for new developments but suggests future research possibilities for reducing energy demand over a building's life cycle.

KEYWORDS _ *Sustainable city development, Urban Simulations, Open-source Spatial Data, CityGML, Life Cycle Assessment (LCA)*

INTRODUCTION

Urban areas are significant contributors to the global climate crisis, emitting substantial greenhouse gases and consuming considerable energy (UN, 2020). In 2021, urban buildings accounted for 30% of the world's final energy use and 27% of energy sector emissions. This included 8% from direct building emissions and 18% from electricity and heat production (IEA, 2021). As urbanization intensifies, challenges like limited space and daylight access are magnified (Dogan et al. 2018).

Combating climate change hinges on sustainable urban development. The European Green Deal, initiated by the European Commission, targets Europe becoming the world's first climate-neutral continent by 2050. It emphasizes energy efficiency, emissions reduction, and sustainable construction practices within the building sector (EC, 2022).

Climate adaptation calls for cross-sector collaboration, with digital tools playing a vital role. Digitalization expedites urban design, fosters data synchronization among stakeholders, and aids vulnerability assessments (IPCC, 2018). Geographic Information Systems (GIS) have the potential to map climate risks, even down to the building level.

The success of digital tool integration relies on data quality and quantity. Europe champions open-source spatial data, with initiatives like INSPIRE and projects like EUBUCCO and the European Data Portal promoting data sharing.

In Norway, open-source spatial data, led by the Norwegian Mapping Authority, has made substantial progress. Open-source tools, including the Norwegian National Data Directory, facilitate data analysis. Yet, challenges in standardization and interoperability persist. However, potentially greater attention and use of existing formats for 3D city models, like CityGML or CityJSON, could improve this challenge (Ledoux et al., 2019).

Knowledge of how to work with spatial data is not enough; it is crucial to comprehend how experts can apply the obtained data. Urban data has a significant role in urban planning, but it is also crucial to assess planned developments. One of the emerging trends in urban planning is the application of LCA methods at the neighbourhood level. Several studies have explored the use of LCA to evaluate neighbourhoods, including energy use, carbon emissions, and other environmental impacts (Harter et al., 2020).

Norwegian legislation, guided by the Planning and Building Act (Plan- og bygningsloven, 2023) and TEK17 (Byggteknisk forskrift (TEK17) med veiledning, 2017) regulations, enforces energy efficiency and environmental considerations in construction. European Union (EU) directives, such as the Energy Performance of Buildings Directive and the EU Taxonomy, promote sustainability in construction, aligning buildings with energy efficiency standards and sustainability objectives (EU Taxonomy, 2023). Notably, LCA at the neighbourhood level is in its initial stages, requiring further research, data, and standardization.

This study evaluates the use of open-source spatial data in Norway for creating 3D neighbourhood models for LCA. It primarily focuses on Norwegian open spatial data, with the possibility of integrating global sources. The study employs software for processing a spatial date, generating a 3D model from it, as well as Urbi+ software for LCA (Harter et al., 2023). The study highlights the significance of CityGML for 3D modelling.

Key challenges include encouraging professionals, particularly architects and planners, to adopt open-source tools, along with addressing integration complexities. The paper aims to establish a workflow for creating 3D CityGML models using available Norwegian data, supporting urban simulations and LCA. Objectives include workflow establishment, offering recommendations for 3D modelling tools in LCA, and presenting case studies on existing and new residential districts in Norway. The research strives to advance LCA methodologies in urban contexts, benefiting urban planners, sustainability assessors, and decision-makers.

THEORETICAL BACKGROUND

The approach presented in this study relies on a set of established approaches and existing sources and software tools, which are briefly listed in the following sections.

Spatial Data sources in Norway, EU and worldwide. Norway's approach to providing public access to spatial data is praised by the United Nations as a best practice. The Norwegian Mapping Authority - Kartverket, plays a vital role in collecting and managing this data, offering a comprehensive dataset, including topography and aerial imagery. Access to this data is facilitated through portals like Geonorge.no, managed by the Norwegian Mapping Authority.

Despite its positive aspects, there's room for improvement in data accessibility, quality control, and transparency, especially for non-experts.

On a European scale, the European Data Portal is a major platform for open data, simplifying access to diverse datasets from across Europe. Globally, OpenStreetMap (OSM) is a collaborative open-source project for creating a free and editable world map. In addition to these sources, various other data providers were considered in this study, highlighting the need for further development and standardization in spatial data formats and tools.

Software tools for processing spatial data have advanced significantly including the next mentioned trends. The development of open-source tools (for example, QGIS, 3difier, GEORES, MashLab, etc.) has gained popularity due to their accessibility, flexibility, and collaborative development. Such tools can be easily used in processing spatial data.

3D modelling tools such as SketchUp, Rhinoceros and Blender allow you to create and analyze realistic 3D representations of spatial data.

Modern software also can easily process a variety of remote sensing data, including satellite imagery, LiDAR, and aerial photography. Feature Manipulation Engine (FME) software, developed by Safe Software, supports operations with the above data, as well as various other formats (e.g., GIS, ESRI Shapefile, non-spatial CSV formats, etc.). The program automates workflows, ensures data quality, and performs complex spatial data transformations.

Development of the tools for LCA of building stock is one of the trends in software as well. (Cabeza et al., 2014) The newly developed tools will enable professionals to conduct comprehensive LCA studies, helping to make informed decisions and drive sustainable architecture and urban planning practices.

LCA at the neighbourhood level is also one of the developing trends. Sustainable development aims to cut resource use and environmental impact, with the construction sector playing a key role in it. Achieving carbon-neutral buildings requires LCAs, to focus on operational energy and emissions as well as the embodied energies and emissions from the heating system components. For example, in "Life Cycle Assessment of Technical Building Services in Large Residential Stocks" (Harter et al., 2020), a method for assessing large building stocks with a focus on heating system components using 3D city models is presented. It describes the methodology for operational energy calculations, heating system components sizing, and LCA of large residential building stocks. Testing on 115,000 Munich (Germany) residential buildings showed potential energy reductions through refurbishment, but carbon-neutral buildings remain a lifecycle challenge.

An approach to evaluate energy demand and emissions in urban districts using 3D urban geometry in CityGML is introduced in "Developing a Roadmap for the Modernization of City Quarters - Comparing the Primary Energy Demand and Greenhouse Gas Emissions" (Harter et al., 2017). It emphasizes refurbishment over reconstruction and the sequence's impact on energy demand.

METHOD

This developed method (Fig. 1) enables the creation of a 3D model from open spatial data in Norway for subsequent LCA. The research aims to advance understanding in this area and derive practical conclusions. The study follows a five-step methodology.

The first step involves defining key parameters such as location (Norway, Fredrikstad, encompassing an existing neighbourhood and new development), the model's purpose (conducting an LCA at the neighbourhood level), and the final 3D model format (CityGML), providing a solid foundation for the modelling process.

The second step is data collection. In the case of this paper existing building datasets and project drawings for new constructions by GRIFF[1] and Arca Nova[2] are included.

The third step focuses on modelling the neighborhood's buildings using specialized software. Different programs are employed for existing and new district portions for the model generating and manual modelling, respectively.

In the fourth step, a unified neighbourhood model in CityGML format is created from 3D building models with the new construction. GEORES software is employed, accompanied by manual adjustments and additional data inclusion needed for the LCA tool of this case (such as construction year and roof type). Urbi+ is used for LCA, incorporating Norwegian weather data, emission values, used HVAC systems, and constructional system definitions.

The last step involves summarizing the case study's results and exploring the potential of the development in the area. LCA data from the new district level is compared with the existing one to assess potential areas for project improvement.

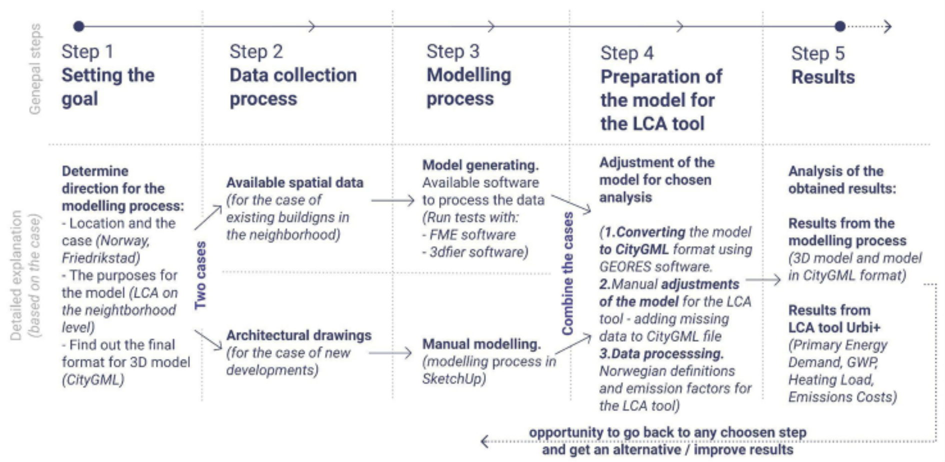

Figure 1: Developed methodology (source: own figure)

Application of Method

Setting the goal. The key parameters of the case for this research are as follows: the area is restricted to the "Verksbyen" area in Fredrikstad, Norway. The area includes an existing neighbourhood and new developments; for the final calculation of the LCA, a file with the CityGML extension is required;

1 Architectural office GRIFF arkitektur: https://griffarkitektur.no

2 Development company Arca Nova: https://www.arcanova.no

the model is also limited to Level of Detail (LoD) 2, which represents building volumes with the big elements like the ground floor, walls, and roof (Fig. 2).

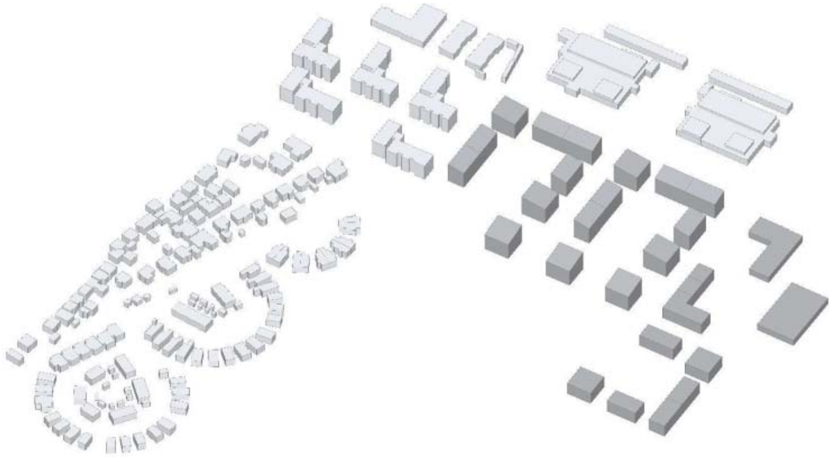

Figure 2: 3D model of the existing buildings (light grey) and new developments (dark grey) in the "Verksbyen" area in Fredrikstad, Norway. Screenshot from SketchUp software.

Data Collection. During the study, Norwegian open data web sources were analyzed: Høydedata, Norwegian Open Data, Geonorge, Kartverket, Norkart, Geodata, and Terratec. Additionally, the European Data Portal as an EU source and OpenStreetMap as a global one was studied.

Modelling process. The modelling process for the case includes the generation of a model of existing buildings from open-source spatial data and the manual modelling of the new developments in the area. The list of software suitable for the case is presented in Table 1.

Table 1: Software used in Verksbyen research case

Software name	Use case	Availability	References
Cloud Compare	View and check LIDAR point cloud data for existing buildings	Open source	www.danielgm.net/cc
QGIS	Extract footprints from OSM footprint data for existing buildings	Open source	www.qgis.org
FME	Generate 3D model for existing buildings from LIDAR point cloud data and building footprint	Commercial	fme.safe.com
3dfier		Open source	tudelft3d.github.io/3dfier
MeshLab	View OBJ file generated from footprint and point cloud data	Open source	www.meshlab.net
SketchUP	Manual 3D modelling for new developed area part of the study	Commercial	www.sketchup.com
GEORES plugin for SketchUP	Generate CityGML file in LoD2	Open source	www.geoplex.de/geores
FZKViewer	CityGML file viewer to check the resulted 3D model	Open source	www.iai.kit.edu/english/164 8.ph
Notepad++	CityGML file code editor	Open source	www.notepad-plus-plus.org
Urbi+	LCA on urban level	Open source	www.github.com/tum-gis/L CA-TGA

Adjustments of the CityGML model for LCA tool urbi+. After creating the CityGML model to utilize the model in the urbi+ LCA tool. The next attributes needed to be added for each building in the model: function of the building, type of roof and year of construction. The models of the buildings are represented as an XML scheme.

To conduct an LCA of the current building stock and scenario for the new development, the establishment of the input parameters for the simulations was done. The calculation's definitions are based on available sources and the assumptions needed are listed in Table 2 to present the methodological approach.

Table 2: Definitions applied into LCA tool Urbi+ for existing neighborhood and new development in the area

Configuration	Existing buildings	New developments	Source of information
Current year	2023	2023	-
Year of Construction Range	1901 - 2019	2020 - 2023	https://geodataonline. map s.arcgis.com
Average Percentage of Heated Top Floors	100 %	100 %	https://geodataonline. map s.arcgis.com
Number to Identify Residential Buildings in CityGML-file	1111	3333	-
Development Period	1901-2019	2020 - 2023	https://geodataonline. map s.arcgis.com
Zip Code	1651	1651	https://www.posten.no
Average Lifespan Buildings	40	-	based on the calculations
Energy Systems Hot Water			
Electric Flow Heaters	80% (RSL = 10 y)	80% (Reference service life (RSL) = 10 y)	https:// energifaktanorge.n o/en/ norsk-energiforsyning / varmeforsyning/ https://www.iea.org/repor ts/renewables-2019/heat
Solar Systems	20% (RSL = 25 y)	20% (RSL = 25 y)	
Energy Systems Heating			
Electric Heaters	100% (RSL = 15 y)	100% (RSL = 15 y)	https://www.iea.org/ fuels- and-technologies/ heating
Pipe System Heating			
Surface Heating	35% (RSL = 50 y)	100% (RSL = 50 y)	https://www.ssb.no/ energi -og-industri/energi/ statistik k/fjernvarme-og-fjernkjolin g/artikler/nye-rekorder-for- fjernvarme
Radiators	65% (RSL = 50 y)		
Reference Service Life (RSL)			

Pipes HP Soil-Water Earth Coll	50 y	-	https://www.base-inies.fr/i niesV4/dist/tableau-de-bor d
Pipes HP Soil-Water Earth Probe	50 y	50 y	
Pipes HP Water-Water	30 y	-	
Pipes Heating	30 y	30 y	
Pipes Hot-Water	40 y	40 y	
Insulation Pipes Heating & DHW	25 y	25 y	
Heat storage Tanks	50 y	50 y	
Oil Tanks	20 y	-	
Additional Parts			
Factor Additional Parts	20 %	20 %	An assumption about the percentage of additional parts

Configuration	**Existing buildings**	**New developments**	**Source of information**
Building Age Classes (BAC) U-values for different building parts			
BAC1(1918); BAC2(1919-1948); BAC3 (1949-1957); BAC4 (1958-1968); BAC7 (1984- 1994); BAC11 (2016+);	Base plate = 0.7; 0.5; 0.36; 0.28; 0.25; 0.1 Floor ceiling = 0.6; 0.4; 0.21; 0.19; 0.16; 0.14 Flat roof = 0.8; 0.5; 0.22; 0.2; 0.18; 0.09 Top floor ceiling = 0.8; 0.5; 0.13; 0.11; 0.09; 0.08 External wall = 1.0; 0.9; 0.35; 0.35; 0.28; 0.13 Wall to earth = 0.7; 0.5; 0.25; 0.22; 0.18; 0.08 U-value win = 2.1; 1.7; 1.7; 1.2; 0.8; 0.5 G-value win =0.7; 0.7; 0.6; 0.5; 0.45; 0.4	Base plate = 0.13 Floor ceiling = 0.5 Flat roof = 0.08 Top floor ceiling = 0.08 External wall = 0.1 Wall to earth = 0.1 U-value win = 0.83 G-value win =0.4 (BAC11 only)	TABULA, Typologier for norske boligbygg - Eksempler på tiltak for energieffektivisering SINTEF, Utvikling av varmeisolasjonsevnen i yttervegger SINTEF, U-verdier Vegger over terreng
Total Primary Energy Factor			
Electricity	0.368	0.368	ISO 2017 – Table B.16 - Weighting factors
Share Renewable (R) & Non-Renewable (NR)			
Electricity	R=92%, NR=8%	R=92%, NR=8%	https://app.electricitymaps.com/map
Op. Costs			
Electricity	0.19 €/kWh	0.19 €/kWh	https://www.strompris.no/ spotpriser
Embodied Costs			
GWP	23 €/t	23 €/t	https://carbonpricingdashb oard.worldbank.org/map_ data

Results. The completed process yielded a 3D neighborhood model, a CityGML model derived from it, and the results for LCA in the text document. This data forms the foundation for informed decision-making, offering opportunities to enhance the neighborhood's sustainability parameters through project revisions and the introduction of details into the existing concept.

RESULTS

Setting the goal. This process laid the foundation for further research steps, defining the spatial and data parameters needed for a comprehensive LCA of the Verksbyen neighborhood. It enhanced the understanding of the area's sustainability and environmental impact.

Data Collection. The datasets listed below were identified as the most accessible and suitable for the case in Verksbyen:

- Høydedata[3] (Norwegian open source) - LIDAR (.LAZ), point cloud data;
- OpenStreetMap[4] (Global, open source) - OpenStreetMap (.OSM), building boundaries data;
- Project documentation from Arca Nova and GRIFF Arkitekten (Partnership access) - Portable document format (.PDF) with the details about the new developments project.

Modelling Process. The results involved the creation of a CityGML model for the area that facilitates subsequent analysis and evaluation in the next step.

Using QGIS, a file containing building footprints for the existing development in the designated area was obtained. This file is crucial for generating 3D models by extruding shapes based on the footprint data. The two 3D modelling processes were produced to generate the 3D model for the site. Here are the outcomes for each of the tested methods:

FME: A workspace was established in FME to generate a 3D model of the neighbourhood. However, the script for processing accurate extrusion of the buildings from point cloud data was left incomplete due to time constraints and the researcher's proficiency in such a program. This method, while less accurate in terms of building heights, produces a file usable for models with lower accuracy requirements.

3dfier: This process adjusted building heights based on the point cloud data, resulting in a more detailed model. It is important to note that despite the correct average building height generated from the point cloud file, the model only displays buildings with flat roofs, even for buildings with pitched roofs. One way or another, the model created in 3dfier was then imported into Sketchup for further development, offering a higher LoD compared to the FME-generated model. Transferring the model to the CityGML standard was the last step of the modelling process. The model from the GEORES plugin for SketchUP includes unique ID records for buildings, with ground floors, walls, and roofs. Viewing and inspection of the created model can be done using the free FKZ viewer software.

Adjustments of the CityGML model for LCA tool urbi+. Regarding the LCA Urbi+ tool, it is important to note that it is currently undergoing improvements and development. When using the tool for calculations, ongoing communication with the program developers is crucial. Ensuring the accuracy of results and their alignment with the CityGML model is also essential. During the calculations for this case, inconsistencies in the results were detected, requiring repeated checks for accuracy validation.

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3 Høydedata web source: https://hoydedata.no

4 OpenStreetMap web source: https://www.openstreetmap.org

Results. The LCA calculation in the urbi+ software generates a text document that presents a variety of calculated indicators essential for LCA. To visualize the results, these indicators are graphically represented using Microsoft Excel software (Fig. 3,4).

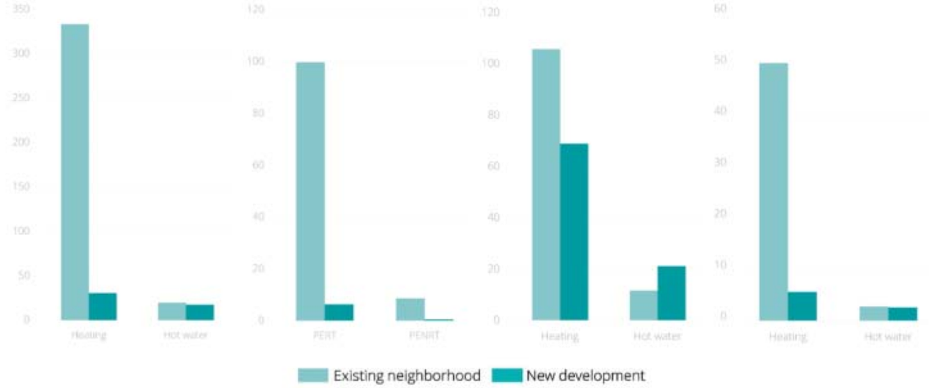

Figure 3: Urbi+ calculation results (from left to right): Average specific final energy demand for heating and DHW [kWh/(m2yr)]; Primary energy from non-renewable (PENRT) and renewable (PERT) resources [kWh/m2]; Heating Load [kW/m2]; Costs Energy for heating and DHW (related to GWP) [€]. The results are presented for both existing neighbourhood and new developments.

Figure 4: Urbi+ calculation results: Total GWP for two cases [kg CO2-eq.]

The benchmark for some of the calculations was the results obtained from the sin.ikia project report, which conducted calculations for a similar new residential neighbourhood (Shahabaldin Tohidi et al. 2022). Table 3 presents key values, notably heating energy requirement closely aligning with sin.ikia's project calculations for the same neighbourhood.

Table 3: Comparison of important calculation data and calculation result for estimated energy needed for heating from Urbi+ tool with the results from syn.ikia for the new developments (Shahabaldin Tohidi et al. 2022)

	syn.ikia demo case	**urbi+ calculations**
Comparison of important calculation data		
Share of renewables	100%	
Types of renewables	Photovoltaics, Ground source heat pump	Photovoltaics, Ground source heat pump

Energy storage: sizes and strategies	DWH, ground, building structure	DWH, ground, building structure, solar thermal collectors
U-values [W/m2K]	exterior wall = 0.1; roof = 0.08; external floor = 0.13; internal floor = 0.50; windows and doors = 0.83	
Heating degree days	4600	
Setpoint for heating and cooling	Heating: 21°C, Cooling: n/a	
Results of the calculations for the new developments in Verksbyen area		
Estimated energy need for heating (space and DHW)	45 kWh/(m2yr)	47,4 kWh/(m2yr)

DISCUSSION

This research adhered to a systematic framework encompassing several critical aspects. It commenced with a meticulous examination of the case study, appraising available datasets and software tools proficient in generating 3D building models from said data. Emphasis was placed on the potential of open data in district-level urban modelling, especially concerning LCA.

The research methodology, having undergone practical application in the Verksbyen neighbourhood case, is expounded upon. The sequential phases of this methodology were elucidated, commencing with the delineation of modelling objectives, advancing to the actualization of 3D modelling, and culminating in the execution of LCA on these models.

The study effectively executed the predefined processes while identifying avenues for future research. While the primary focus was on two key data sources, it is acknowledged that there are other sources warranting exploration for 3D model creation that could be used. This research also delved into software tools like QGIS, FME, 3dfier, and Sketchup, with FME demonstrating considerable potential for further modelling investigations. Notably, 3dfire expedited the production of swift, albeit low-detail models tailored to specific needs.

LCA computations within urbi+ necessitated supplementary data and collaboration with the program's developer. This underscores the pivotal role of readable and compatible datasets for both 3D modelling and LCA software. It is noteworthy that the outcomes derived from urbi+ calculations can be employed to enhance urban design in various places.

Regarding recommendations, prospective development should explore the utilization of open spatial data for modelling and assess the other varieties of 3D modelling techniques. Although the described methodology has been produced and applied, more similar studies are needed to improve the accessibility and implementation of the process and ongoing development of the trends in LCA at the urban level necessitates further examination.

In summation, this paper offers a comprehensive exposition of the processes entailed in 3D modelling and LCA employing diverse software applications. It provides reflective insights, pertinent references, and salient recommendations for practitioners, encompassing the adoption of open spatial data in modelling, the efficacy of 3D generation methodologies, and the popularization of the LCA at the neighbourhood level.

LIST OF ABBREVIATIONS

3D	Three-dimensional
BAC	Building Age Class
CityGML	City Geography Markup Language
CityJSON	City Java Script Object Notation
CSV	Comma-separated values
FME	Feature Manipulation Engine, Software for integrating spatial data
GIS	Geographic information system
HVAC	Heating, Ventilating, and Air Conditioning
LCA	Life Cycle Assessment
LiDAR	Light Detection and Ranging
LoD	Level of detail
OSM	Open Street Map
XML	Extensible markup language

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