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Analyzing the Feasibility of Integrating Urban Sustainability Assessment Indicators with City Information Modelling (CIM)

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Abstract: Sustainability assessment methods have gained the attention between urban planners and policymakers since they promote a comprehensive view of the cities. Intelligent solutions, enabled by advances in information technologies, can accelerate progress in achieving sustainability goals. In this context, City Information Modelling (CIM) emerges as a tool to facilitate urban sustainability assessment implementation. Accordingly, the main question aimed to address in this article is whether conventional sustainability assessment tools can be adapted to the CIM framework. In this regard, this study extracts the most consensual list of indicators from four sustainability assessment methods: BREEAM-C, LEED-ND, SNTool, and SBTool^{PT} Urban, to identify a clear set of key sustainability priorities. The selected sustainability assessment methods are pioneering and often used for performance assessment at the urban scale. Furthermore, the indicators extracted from the assessment methods are measurable and can present accurate results. The study analyses the potential of the selected indicators to be calculated in CIM. The final product of the article is identifying the indicators that are adaptable to be used in the CIM approach.

Keywords: city information modelling; urban sustainability assessment methods; urban sustainability indicators

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1. Introduction

Analyzing how cities use natural resources, energy and water shows three of the most important aspects of the sustainability of urban public services and businesses. This is while cities produced over 50% of global waste, and 60–80% of global greenhouse gas emissions [1]. The complexity and interconnectedness of social, economic, and environmental issues in cities have caused a growing emphasis on sustainability in urban planning and development [2]. Local authorities and urban decision-makers have the opportunity to apply the improvements that reduce resource needs and environmental impacts. Cities can play an essential role in sustainable development, offering opportunities and being great instruments for change and improvement of quality of life [3,4]. This has led to the development and application of urban sustainability assessment methods, which have gained momentum especially since specific urban indicators were created through Agenda 2030 [5] to address social, economic, and environmental issues. Sustainability assessment methods can assist in identifying alarming vulnerabilities in environmental deficiencies of the buildings and the built environment, as well as socio-economic inadequacies of neighborhoods [6]. However, as focusing on individual buildings ignores the impact of the building sector in a broader view of the environment, sustainability initiatives which initially focused on building-scale developments, subsequently evolved further towards neighborhood-scale developments [7].

The sustainability assessment methods develop through their inherited indicators, which identify criteria and address fundamental issues. In fact, the indicators are data carriers, such as conceptualizing phenomena and highlighting trends, simplifying, quantifying, and analyzing complex information. However, one single issue can be assessed by various indicators and addressing a variety of aspects [8]. Therefore, compiling a short and comprehensive list of indicators to create a common vision of the predominant environmental issues and crises is a necessary step toward sustainable development goals. Some of the internationally well-known systems for sustainability assessment of urban communities are BREEAM Communities (BREEAM-C), LEED for Neighborhood Development (LEED-ND), and Sustainable Neighborhood Tool (SNTool) from iiSBE. Each assessment method has its advantages and disadvantages, making the comparison of several methods assists in overcoming the strategies' weaknesses while highlighting their common environmental concerns [6], and helps for developing more accuracy in predicting outcomes, monitoring, and reinforcing the progresses toward the targets. However, many variables are used in each assessment method, making it unlikely to compare the entire variables, but comparing a limited number of variables is more desirable. Besides this, implementing urban sustainability assessment systems, in their traditional way, can be time-consuming, bureaucratic, and complicated. Given the abundance of complex urban data, city managers can easily become overwhelmed. Therefore, it is recommended that they employ modern technologies, systems, and tools to overcome the growing demands and challenges of sustainable development in cities [9,10]. Sustainability was once the most widely accepted urban concept but has been overtaken in popularity by "smart cities" in the past decade [11]. This reveals that the original concept of sustainability, introduced in 1987, has become outdated due to the needs of our highly digitalized society [11]. However, there is currently an active stream of academic discussion analyzing how smart solutions can help achieve balanced sustainability in cities [2,12]. This has led to the emergence of a new concept known as "smart sustainable cities", driven by integrating smart technologies and solutions with traditional infrastructure management practices by using data analytics, real-time monitoring, and predictive modeling [13]. This enables city managers to make informed decisions that optimize resource utilization, reduce waste, and improve service delivery to citizens.

In this regard, one tool that has gained momentum by using up-to-date technologies is City Information Modelling—CIM [14,15]. By integrating the different components of the urban environment, the CIM model can help improve planning, designing practices, and implementing sustainable strategies [14,16]. Accordingly, information models for urban spaces, such as CIM, can store and provide data effectively, allowing city planners and urban designers to analyze cities' demands, and make more efficient, effective, and sustainable plans [17]. By incorporating the sustainability analysis criteria into a CIM model, assessments can be more accurate, faster, and easier to manage. Thus, integrating the analysis of urban sustainability into a CIM model can bring great benefits, such as greater adoption of assessment systems, ease of implementation, and present sustainable options as drivers of decision-making.

Therefore, this study made a comparative analysis of the internationally well-known systems, focused on identifying the prioritized established aspects and issues, to demonstrate the existing sustainability concerns among the urban sustainable assessment methods. Consequently, the aim is to evaluate the possibility of adopting the most prioritized indicators to the CIM context for assessing urban sustainability, considering the Portuguese methodology SBTool^{PT} Urban as a baseline and evaluating how many indicators could be calculated using CIM.

The concept of City Information Modelling has gained attention in the literature in the last decade. The number of publications about the topic has been growing year after year, and considering this trend, the expectation is continuing growth [14–16]. Considering the novelty of the CIM concept, several approaches are presented in the literature. Overall, the concept is linked to urban digital models with rich geospatial information, and a complete and updated database [14–16,18].

Kehmlani [17] stated that CIM is analogous to BIM, but on an urban scale. The main idea is to have an intelligent city model, that can assist in the planning, design, and analysis of different aspects of the city. Almeida and Andrade [19] considered CIM as a computer-based model, involving processes, policies, and technologies, that allow multiple stakeholders to collaborate in the development of a sustainable, participatory, and competitive city. Dall'O, Zichi, and Torri [20] defined CIM as "the latest advance from BIM", where data is available in a 3D environment, including various components of the city. This tool could be used by architects and urban planners, city users, policymakers, and City Councils. All the stakeholders can collaborate and make decisions based on city data. Wang and Tian [21] defined CIM as "an organic synthesis of a three-dimensional urban spatial model and urban information". Moreover, the authors highlighted that the CIM concept is closely related to smart cities, integrating the Internet of Things (IoT), Geographic Information Systems (GIS), and Building Information Modelling (BIM), among other technologies. Even though the term CIM is under discussion and there is not a widely adopted concept, it is noticed the relationship between CIM, BIM, and GIS, and many authors investigating possibilities for integration of GIS and BIM to compose a CIM platform [14–16,21,22]. In line with this trend, this study defines CIM as an integration of GIS and BIM technologies.

Just as the concept of CIM has several approaches in the literature, there is also no single definition regarding the CIM platform. Beirão [23] describes a methodology for using a CIM platform, that it should be open, accessible, and interactive for all users, whether urban planners or citizens. Almeida and Andrade [19] aligned with this approach emphasizing the collaboration between multiple stakeholders. According to Stojanovski [24] the CIM platform should evaluate the multiple scales of the city. Moreover, the author highlighted that it should be a design and planning tool, where urban planners and designers could share properties, characteristics, and relationships of urban elements. Although there are diverse approaches, some common elements characterizing a CIM platform: interactivity, collaboration, interoperability, shared information among the stakeholders, also, BIM and GIS integration.

2. Materials and Methods

The objective of this paper is to evaluate the possibility of using CIM for assessing urban sustainability, by adopting the most prioritized indicators and using the Portuguese methodology SBTool^{PT} Urban as a baseline method. In order to fulfill this goal, the work was divided into two parts: a comparative analysis of the environmental concerns periodization, and an evaluation of the potential of CIM to assess the urban sustainability concerns.

Comparative analysis is the process of comparing different items of the selected sustainability assessment methods to distinguish their similarities and differences. Since there are many variables used in each method, it is also unlikely to compare the entire variables. Instead, comparison in this study focused on aspects and issues, which are defined by the indicators of the selected method to identify the significant aspects prioritized by the majority of them. In the next step, for the evaluation of the potential of CIM to assess urban sustainability indicators, a CIM platform is proposed to make the calculation of the indicators. Then an in-depth study of the chosen most prioritized indicators is carried out, focusing on the analysis of the type of data to be modeled, the feasibility to model and access the information, and similar cases in the literature.

For the first part, the present categories of SBTool^{PT} Urban are considered as a baseline, comparing them with the similar indicators of the selected methods, including Sustainable Neighborhood Tool (SNTool) from iiSBE, BREEAM Communities (BREEAM-C), LEED for Neighborhood Development (LEED-ND). Moreover, the alignment of the indicators with the goals of Sustainable Development Goals (SDGs), ISO 37120 standards, and Level(s) are defined. Since the strategies developed for buildings consequently affect the urban environment, therefore the study selected Level(s) as well, which has a clear set of prioritized performance indicators for six areas of sustainability, contributing to EU policy goals. For this purpose, 522 indicators provided by the selected methods are compared by categorizing them in the tables, and the indicators with similar issues and objectives have been selected and re-categorized, based on the categories of SBTool^{PT} Urban. The frequency of use of the indicators among the selected methods is shown in Figure 1. The indicators in the analyzed methods have different titles, but address similar issues and aspects, being considered the same and organized under the same category. If an indicator (e.g., District Heating and Cooling) was not covered in the baseline category, it is added to the list. The study recognized a total of 51 indicators, grouped into 14 categories, as the most prioritized and promoted indicators among the studied major sustainability assessment methods, which are necessary to be assessed in every urban development.

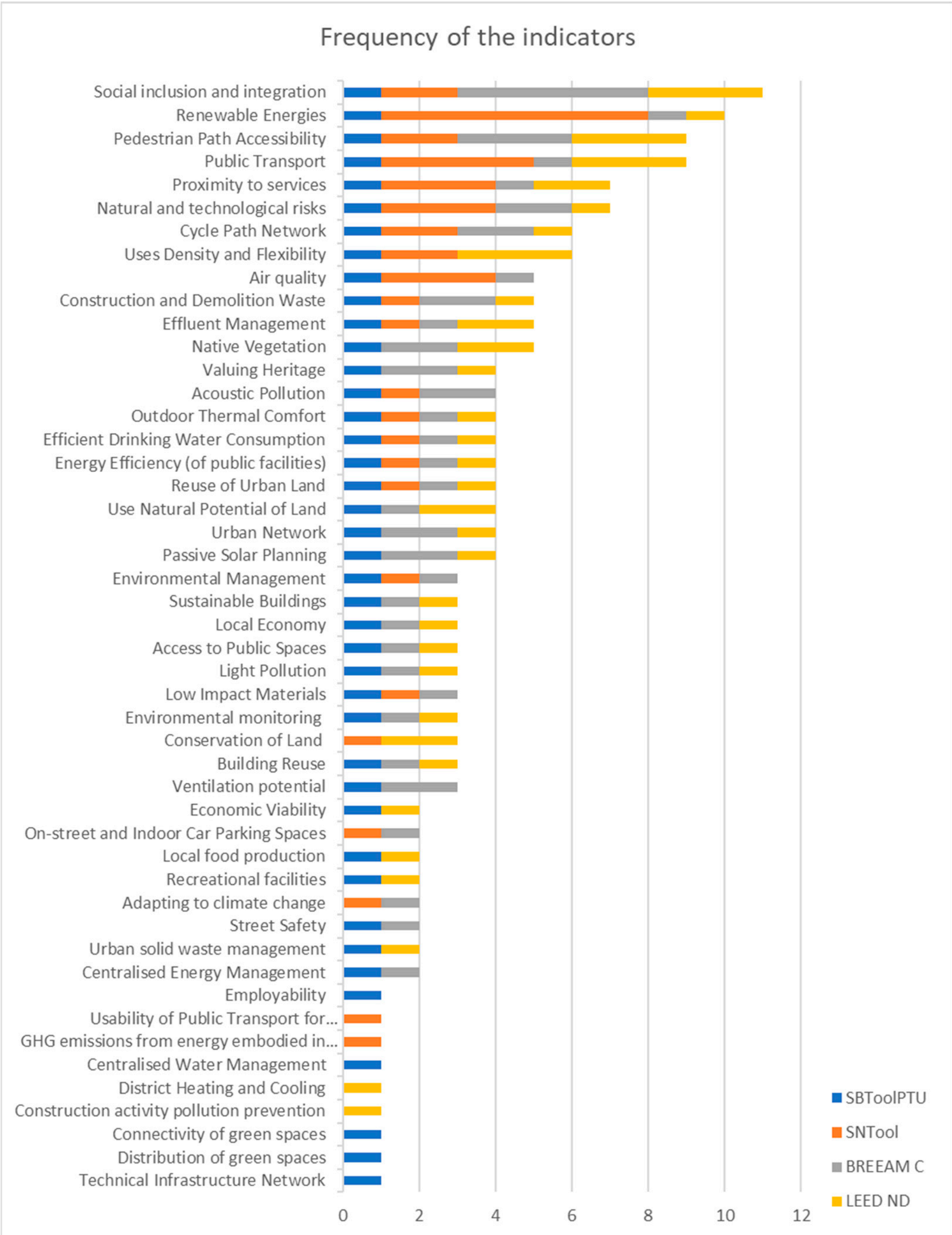

Figure 1. The frequency of use of the indicators among the selected sustainability assessment methods.

For the next part, the assessment of the indicators using CIM, first, different tools and software are evaluated to compose a CIM platform for the calculation of the indicators. Aligning with the trend presented in the literature, associating CIM with the integration of GIS and BIM, this study considered the use of BIM tools with the incorporation of GIS information, also tools that can perform calculations through a digital model. The following evaluation criteria are used to define the appropriate tool: literature review; case studies using BIM and GIS and sustainability assessment systems; flexibility and adaptability to calculate the criteria; the relationship between the tool and CIM; type of tool's access (free access or subscription). To minimize the interoperability problems, the CIM platform proposed by this study is based on the use of Autodesk Revit and tools that can be used inside the software. Therefore, the selected tools are Autodesk Revit as a BIM tool, the online tool CADMAPPER, to incorporate GIS information into the model, and the visual program tool Dynamo, to perform the calculations. The use of Dynamo, as a Revit plug-in, allows the user to create routines or programs to execute activities, and calculations, among other functionalities. It is a flexible and adaptable tool, which is important to perform the calculation of indicators. Once the CIM platform is defined, the second phase is the modeling phase. At this point, all the necessary data is added to the model. CADMAPPER is the tool used to insert the urban area into the model, then it is necessary to characterize the areas, and create the property parameters, materials, topography, project information, and shared parameters. After the modeling phase, the calculations are performed by Dynamo, where the indicators are quantified, and calculation routines are created. Each indicator has a different calculation routine, depending on the indicator's calculation parameter(s). This study has adopted the SBTool^{PT} Urban methodology as a baseline, thus the calculation method has followed the SBTool^{PT} Urban indicator's calculation methodology.

After defining the CIM platform, a second analysis is performed, by identifying the possibility of the chosen prioritized indicators being calculated through the CIM. Since the SBTool^{PT} Urban methodology covers most of the predominated sustainability indicators (41 out of 48), this study used the calculation method of SBTool^{PT} Urban indicators to evaluate the feasibility of calculation through the CIM. Taking into consideration the assessment process, each indicator and its parameters are verified according to the calculation criteria and methodology, and the possibility to be integrated into a digital information model. Consequently, the indicators are classified as 'YES', 'NO', or 'PARTIALLY. A parameter is considered 'YES' based on the data type, the feasibility to be modeled, and the availability of the required information and similar cases in the literature. A parameter is classified as 'NO' if the necessary information to be calculated could not be modeled, is not found in any related case study, or the parameter will not benefit greatly from the CIM. And 'PARTIALLY' means that most of the criteria could be assessed by using the model, but one or two criteria cannot be assessed. Once the new indicators do not have a calculation methodology established, they were considered "NON-APPLICABLE".

According to the SBTool^{PT} Urban methodology, the assessment process is implemented in three stages, including quantifying the performance at the indicator level, quantifying the performance at the level of categories, and sustainability dimensions, and finally, emitting the Sustainability Certification. The scope of the present study is the first stage of the assessment process, quantifying the performance at the indicator level.

3. Results and Discussion

3.1. The Aspects of Sustainability which Matter the Most

Analyzing the indicator averaging reveals that the evaluated sustainability assessment methods vastly have promoted similar sustainability concerns [25]. However, different methods have varying emphases on different issues, in weighting and ratings, and the mandatory or prerequisite indicators are different in each method. In overall, the issue of Mobility has devoted the highest number of indicators, and subsequently, the issues related to Local and Cultural Identity, Land Use and Infrastructure, then the issues of Energy, and Outdoor Comfort are subsequently the second, and third in the list of importance. Urban

Form and Amenities are the fourth ones in terms of importance, and the next are Water, Material and Waste, and then the issues related to Security (Natural Risks), and Social issues (Employment and Economic Development). Figure 2. indicates the frequency of the sustainability issues based on the different categories addressed by the assessment systems, ISO 37120, Level(s), and the SDGs. However, the studied methods have allocated a different number of indicators for assessing the different sustainability issues, which are respectively defined, below:

- SNTool: Energy, Mobility, Outdoor Comfort, Amenities, and Security (Adaption to Climate Changes);
- BREEAM-C: Local and Cultural Identity, Urban Form, and Mobility;
- LEED-ND: Land Use and Infrastructure, Mobility, and Local and Cultural Identity;
- SBTool^{PT} Urban: Land Use and Infrastructure, Ecology and Biodiversity, and Outdoor Comfort.

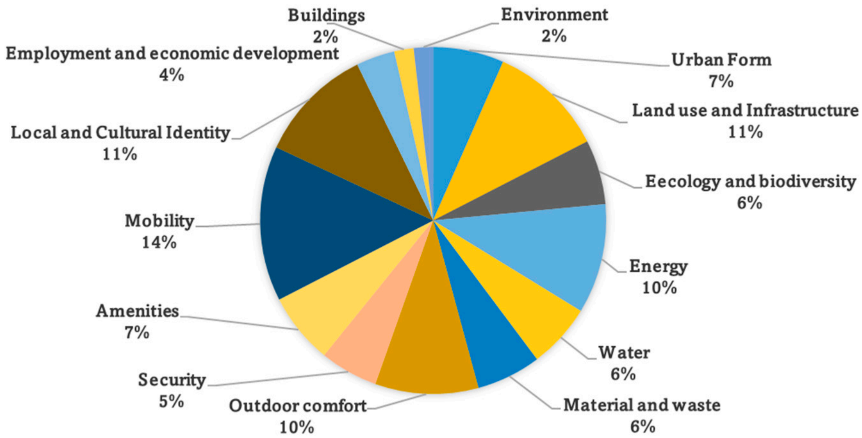

Figure 2. The frequency of sustainability issues based on the categories.

Moreover, the study finds out that the most predominated sustainability indicators necessary to be assessed in every urban context totally including 48 indicators, of which 41 indicators are covered by the SBTool^{PT} Urban and a total of 7 indicators are not covered or partially covered. To be noted, some of the selected indicators of the final list are defined only by one method but addressed in one or more sustainability global strategies (i.e., Level(s), ISO 37120, or the SDGs of Agenda 2030).

3.2. *Analysis of CIM's Potential for the Calculation of the Indicators*

For this analysis, the indicators were evaluated considering the calculation methodology of SBTool^{PT} Urban, as well as similar case studies, found in the literature review. Accordingly, indicators can be calculated through a verification checklist, where points are attributed for each criterion in the list, or by calculating the ratio between the criteria of the indicators. Each indicator has, at least, one parameter to be calculated.

3.2.1. The indicator to measure Passive Solar Planning

This indicator promotes maximization of exposure of the buildings to the sun, promoting shading in summer, and minimizing it in winter. It has been promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, while addressed in Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, this indicator is calculated through a verification checklist. The criteria of the list are related to the percentage of buildings' exposure to the sun. As Autodesk Revit allows sun exposure evaluation, this indicator is adaptable in the CIM model. The calculation can be performed by applying a Dynamo routine. An example is developed by Tao and Qian [26], who have presented a case study where a BIM model is used to evaluate solar exposure, ventilation, and energy consumption.

3.2.2. The Indicator to Measure Ventilation Potential

This indicator promotes the distribution of buildings to provide natural interior ventilation, by enhancing the use of prevailing winds. It has been promoted by SBTool^{PT} Urban and BREEAM C, while addressed in Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. The calculation method indicated in SBTool^{PT} Urban Guide is through the verification checklist. The criteria of the list are related to the distribution, location, and orientation of the buildings, and their relationship with the prevailing winds. Luo, He, and Ni [27], and Sabri et al. [28] studies have demonstrated the viability of calculating similar criteria using urban digital models. Thus, this indicator is adaptable in CIM, and the calculation can be performed by applying a Dynamo routine.

3.2.3. The Indicator to Measure Urban Network

This indicator promotes connectivity between roads of different hierarchies on a more human scale, reducing distances, and facilitating circulation for pedestrians and cycling in daily travel. It has been promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed in SDGs. Therefore, the study has recognized this indicator as a prioritized environmental concern. To calculate this indicator, the SBTool^{PT} Urban Guide indicates two calculation parameters: the Real Intersections Index and the Connectivity Promotion Index, the result is the Urban Network Index obtained by the weighting of the two parameters. The first parameter is obtained by the ratio between the number of intersections and the urban area studied. This calculation can be done through the BIM model and the use of Dynamo's routine. The second parameter is calculated through the verification checklist. The criteria established by the list are measurable and can be obtained through the information model. In this case, the Dynamo routine can attribute the points for each criterion. Thus, this indicator is adaptable in CIM.

3.2.4. The Indicator to Measure the Used Natural Potential of Land

This indicator encourages the appropriate use of the land according to its natural potential. It has been promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, to calculate this indicator is necessary to sum the areas appropriately used according to their natural potential and make the ratio with the studied area. The requirements for land use and the properties of each area can be added to the digital model using Dynamo [29]. When the areas are defined in the model, a Dynamo routine can be performed for calculation [30]. This indicator is identified as adaptable in CIM, as well.

3.2.5. The Indicator to Measure the Used Density and Flexibility

This indicator encourages land-use efficiency, diversity of uses, and increase density through the building height. It has been promoted by SBTool^{PT} Urban, SNTool, and LEED ND, while addressed by ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. The SBTool^{PT} Urban Guide indicates two calculation parameters for this indicator: the Percentage of Land Use Efficiency and the Percentage of Areas with Flexibility of Use. The first one is calculated by the ratio of the number of inhabitants and the building footprint area. The second is calculated by the ratio of the areas with flexibility of use and the project area. The study found out both parameters can be calculated using the digital model, once the criteria can be assessed by the model, and applying a Dynamo routine to perform the calculations.

3.2.6. The Indicator to Measure the Reused Urban Land

This indicator promotes the reuse of previously built land areas and land recycling. It has been promoted by SBTool^{PT} Urban, SNTool, and BREEAM C, and addressed by SDGs, which made it to be recognized as a prioritized environmental concern. In order to calculate this indicator, based on the SBTool^{PT} Urban Guide, it is necessary to identify the ratio between the contaminated lands which is rehabilitated and reused, and the total area of contaminated lands. The study found the possibility of calculating this ratio by applying a Dynamo routine since the areas (e.g., contaminated areas to be rehabilitated and reused) are characterized in the model.

3.2.7. The Indicator to Measure the Building Reuse

This indicator promotes the reuse of buildings. This indicator is promoted only by SBTool^{PT} Urban, while addressed in SDGs, which made it to be recognized as a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, this indicator is calculated through the ratio between the built area to be reused or rehabilitate and the total built area. The calculation method using the CIM model is performed in two phases, at first, all the buildings must be characterized in the model, and then the rehabilitated buildings must be identified. The results can be provided by the Dynamo routine.

3.2.8. The Indicator to Measure the Technical Infrastructure Network

This indicator promotes the optimization of technical infrastructures. This indicator is promoted only by SBTool^{PT} Urban, while addressed in SDGs, which made it to be recognized as a prioritized environmental concern. The calculation is made by the ratio of the length of technical infrastructure to be reused and the total length of the technical infrastructure network. This calculation can be performed by using the CIM model, identifying the infrastructure network, and then applying it to a Dynamo routine.

3.2.9. The Indicator to Measure the Conservation of Lands

This indicator encourages the conservation of the proportion of lands, considered to be of value for ecological or agricultural purposes, to remain undeveloped. This indicator is promoted only by SNTool, and LEED ND, and addressed in ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. However, as this indicator is not promoted by SBTool^{PT} Urban, analyzing its applicability for the CIM calculation is out of the scope of this study. Even though, a further study could be made when the benchmarks and calculation methods have been defined.

3.2.10. The Indicator to Measure the Distribution of Green Spaces

This indicator promotes the distribution of green space in the sites. This indicator is promoted only by SBTool^{PT}_U, and addressed in ISO 37120, and SDGs, making it recognized as a prioritized environmental concern. This indicator can be calculated through the CIM. The calculation methodology is described in Section 3.3 of this study.

3.2.11. The Indicator to Measure Connectivity of the Green Spaces

This indicator promotes the connectivity of green spaces on the site and is promoted only by SBTool^{PT} Urban, but addressed in SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, this indicator is calculated by the ratio of the area of green spaces connected and the total green area of the site. This calculation can be performed by using the model and applying a Dynamo routine.

3.2.12. The Indicator to Measure Native Vegetation

This indicator promotes the conservation or cultivation of native vegetation on the site. It has been promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. Similar to the previous two indicators, this indicator is calculated by the ratio of the green area with native vegetation and the total green area. For this purpose, the green areas of the site must be defined in the CIM model, and then a Revit family of "native plants" must be created and attributed to the specific areas. This calculation can be performed by the Dynamo routine.

3.2.13. The Indicator for Environmental Monitoring

This indicator promotes land-use efficiency, diversity of uses, and increase density through the building height. It has been promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, while addressed by ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. The calculation methodology provided by the SBTool^{PT} Urban Guide is through a verification checklist. To comply with the list, an Environmental Monitoring Plan must be developed. In this case, based on the findings of the study, this indicator is not possible to be calculated though using the CIM model, as the criteria cannot be added and assessed by the model.

3.2.14. The Indicator to Measure Construction Activity Pollution Prevention

The purpose of this indicator is to reduce pollution related to construction activities. This indicator is promoted only by LEED ND but addressed in SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. This indicator is not promoted by SBTool^{PT} Urban, so it is considered not applicable for the CIM calculation analysis. However, a further study can be made when the benchmarks and calculation methods have been defined.

3.2.15. The Indicator to Measure Energy Efficiency (of the Public Facilities)

This indicator encourages energy efficiency in public spaces, by reducing energy consumption and energy-consuming systems (i.e., public lighting and dynamic control systems). It has been promoted by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, while addressed by ISO 37120, and SDGs. Therefore, it is recognized as a prioritized environmental concern. In the case of this indicator, the SBTool^{PT} Urban Guide indicates a verification checklist to calculate it. The list's criteria could be "PARTIALLY" calculated through the CIM. The first criterion is a Monitoring and Maintenance Plan, and similar to the Environmental Monitoring indicator, this criterion cannot be assessed through the CIM model. However, the other criteria can be calculated using the model and the Dynamo routine.

3.2.16. The Indicator to Measure Renewable Energies

This indicator promotes local renewable energy production or the availability of renewable energy sources in the region. It has been promoted by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, while addressed by Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. According to SBTool^{PT} Urban Guide, this indicator can be assessed by calculating the ratio of the renewable energy produced locally per the total estimated energy consumption for the project. To calculate this indicator through the CIM model, the energy data and the estimated energy consumption must be added to the model, and then the calculation can be performed by Dynamo routine. In their study, Padsala and Coors [31] analyzed similar parameters, proposing a CIM platform to evaluate renewable energy production and building energy consumption in an urban area in Aldingen, Germany.

3.2.17. The Indicator to Measure District Heating and Cooling

This indicator promotes energy management systems in the systems that use energy in public spaces. It has been promoted by SBTool^{PT} Urban, and BREEAM C, and addressed by SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. SBTool^{PT} Urban Guide indicates a verification checklist for the calculation of this indicator. The study found out that not all the criteria of this indicator can be calculated through the CIM model (e.g., Energy Management Goals), but some criteria, such as the electrical energy network measurement, could be assessed and calculated. Therefore, this indicator is considered "PARTIALLY" applicable in CIM.

3.2.18. The Indicator to Measure the Centralized Energy Management

This indicator promotes using district heating and cooling strategies that reduce energy use and energy-related environmental harms. This indicator is promoted only by LEED ND but addressed in SDGs, making it recognized as a prioritized environmental concern. However, as this indicator is not promoted by SBTool^{PT} Urban, analyzing its applicability in CIM is out of the scope of this study. A further study can be made when the benchmarks and calculation methods are defined.

3.2.19. The Indicator to Measure the Efficiency of Water Consumption

This indicator promotes using water conservation practices and reduces water consumption in public spaces, by simultaneously reducing the production of effluents and pressure in the drainage systems. This indicator is promoted by SNTool, BREEAM C, and LEED ND, and addressed by Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a prioritized environmental concern. In the SBTool^{PT} Urban Guide, the calculation of this indicator is made by using a verification checklist. Most of the list's criteria have the possibility of being calculated using a CIM model. However, the criterion for establishing an education program cannot be calculated through the CIM. Thus, the indicator is considered "PARTIALLY" applicable in the CIM model.

3.2.20. The Indicator for Effluent Management

This indicator promotes the recharge of underground reserves, reducing the risk of flooding and the load on public drainage and effluent treatment systems. It also promotes the adequate dimensioning of domestic wastewater treatment systems, responding to the demands generated by the project. This is addressed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by Levels, ISO 37120, and SDGs, making it a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, there are two parameters to calculate this indicator: the Percentage of Infiltration Areas and the Effluent and Soil Permeability Index. The first parameter is obtained from the ratio of Permeable Areas and the Total Intervention Area. It can be calculated through the CIM model, by determining the permeable areas, and then applying it in a Dynamo routine. The second parameter is determined by a verification checklist. For this stage, although the criteria can be added to the CIM model, the list is based on two plans, including Effluent Management Plan, and Water Management Plan, which cannot be assessed through the model. Thus, this parameter is considered "NO" regarding its applicability to CIM modeling.

3.2.21. The Indicator for Centralized Water Management

This indicator encourages the control of water consumption and centralized water systems. This is promoted only by SBTool^{PT} Urban, but ISO 37120 and SDGs address it, which has led to it being recognized as a priority environmental concern. The SBTool^{PT} Urban Guide provides a verification checklist to calculate this indicator. In this checklist, most of the criteria can be calculated using the CIM model, and the points can be determined by applying a Dynamo routine. Despite this, the CIM model cannot assess the criteria associated with energy goals and results dissemination. A CIM assessment is considered to be "PARTIALLY" appropriate for this indicator.

3.2.22. The Indicator to Measure Using Low-Impact Materials

This indicator promotes the use of sustainable materials in public spaces. SBTool^{PT} Urban, SNTool, and BREEAM C encourage these practices, while Levels and SDGs address them. Therefore, this indicator is recognized as a high-level environmental concern. In the SBTool^{PT} Urban Guide, the calculation of this indicator is made by the ratio between the total areas using low-impact materials and the total floor area. This calculation can be made in the CIM model, by applying a Dynamo routine. The model can be used to identify materials and quantities, albeit a materials database should be created in order to assess the information contained therein.

3.2.23. The Indicator to Measure Using Construction and Demolition Waste (CDW)

The indicator recommends reusing construction and demolition waste on the site. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a critical environmental concern. For this indicator, the SBTool^{PT} Urban Guide establishes two calculation parameters: the Percentage of Recycled CDW Incorporated, and the CDW Valorization Index. The first parameter, the ratio between the weight of CDW incorporated into materials and the total CDW weight is calculated. For this, it is necessary to create a materials database, and then it is necessary to characterize the CDW incorporated into the materials. This stage is applicable to CIM, and the ratio is obtained using Dynamo. The second parameter is calculated using a verification checklist, but most of the criteria on the list cannot be assessed using the CIM model. As a result, the parameter is considered to be "NO" in terms of its applicability to CIM.

3.2.24. The Indicator for Urban Solid Waste Management

This indicator promotes the selective separation of waste and the implementation of recovery systems. This is encouraged by SBTool^{PT} Urban, and LEED ND, and addressed by Levels, ISO 37120, and SDGs, making it a prioritized environmental concern. According to the SBTool^{PT} Urban Guide, this indicator is calculated through a verification checklist. Nevertheless, the study found that the criteria on the list cannot be assessed through CIM, and therefore the indicator is classified as "NO".

3.2.25. The Indicator to Measure GHG Emissions from Energy Embodied in Construction Materials

This indicator promotes measuring the embodied non-renewable primary energy of materials used for building construction. This is only encouraged by SNTool but also addressed by Levels, ISO 37120, and SDGs, which made it to be recognized as a prioritized environmental concern. This indicator is not promoted by SBTool^{PT} Urban, so it is considered not applicable for the CIM calculation analysis in this study. In spite of this, further research can be conducted once benchmarks and calculation methods are defined.

3.2.26. The Indicator to Measure Air Quality

In accordance with this indicator, outdoor air quality can be assessed in order to reduce pollutants in outdoor spaces. This is developed by SBTool^{PT} Urban, SNTool, and BREEAM C, and addressed by Levels, ISO 37120, and SDGs. Therefore, this indicator is recognized as a critical environmental concern. The SBTool^{PT} Urban Guide establishes a verification checklist to calculate this indicator. The CIM model cannot evaluate all of the criteria on the list, and the indicator is classified as "NO" based on the findings of the study.

3.2.27. The Indicator to Measure Outdoor Thermal Comfort

This indicator promotes improving the comfort of inhabitants in outdoor spaces of the site and assessing the percentage of spaces that provide thermal comfort. This is encouraged by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and also addressed by Levels. Therefore, this indicator is recognized as a high-level environmental concern. According to the SBTool^{PT} Urban Guide, there are two calculation parameters to determine this indicator. The first is the Percentage of Spaces with Thermal Comfort, which is determined by the ratio between the sum of the areas that promote thermal comfort and the total intervened area. This parameter can be calculated using the CIM model, while it is necessary to characterize all the areas and then apply a Dynamo routine to calculate it. Additionally, the second parameter is calculated through the verification checklist, in which the criteria can be assessed using the CIM model, and the points can be attributed using Dynamo.

3.2.28. The Indicator to Measure Acoustic Pollution

This indicator encourages the reduction of outside noise to enhance the acoustic comfort of the site's residents. This indicator is only available in SBTool^{PT} Urban, SNTool, and BREEAM C, and is addressed by Levels and ISO 37120, which makes it a priority environmental concern. In the SBTool^{PT} Urban Guide, this indicator is determined through a verification checklist. However, as the criteria on the list cannot be assessed through the CIM model, the indicator is classified as "NO".

3.2.29. The Indicator to Measure Light Pollution

A key objective of the indicator is to reduce light pollution by optimizing the design of public lighting and reducing glare and intrusive light (inside homes). It is promoted by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by Levels. Therefore, this indicator is recognized as a high-level environmental concern. The SBTool^{PT} Urban Guide establishes a verification checklist to calculate this indicator. Based on the findings of the study, although some of the criteria can be calculated using a CIM model, the majority of the criteria cannot be assessed. Thus, this indicator is classified as "NO", regarding its applicability to CIM.

3.2.30. The Indicator to Measure Street Safety

This indicator promotes recommendations for crime prevention measures. This is encouraged by SBTool^{PT}_Urban, and BREEAM C, and addressed by the SDGs, making it a prioritized social dimension of sustainability concern. The calculation methodology for this indicator in the SBTool^{PT} Urban Guide is a verification checklist. As with the previous indicator, the criteria of the list cannot be assessed by the CIM model based on the findings of the study. In view of its applicability to CIM, this indicator is classified as "NO".

3.2.31. The Indicator to Measure Natural and Technological Risks

This indicator promotes recommendations for the safety of the population and access to procedural information in the event of natural and technological disasters. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by Levels, ISO 37120, and the SDGs. Therefore, this indicator is recognized as a crucial social dimension of sustainability concern. Similar to the previous two indicators, the SBTool^{PT} Urban Guide establishes a verification checklist to calculate this indicator. Based on the findings of the study, the criteria cannot be assessed through the CIM model. Accordingly, this indicator is classified as "NO" with regard to its applicability to CIM.

3.2.32. The Indicator to Measure Adaptability to Climate Change

The purpose of this indicator is to determine whether the development is resilient to climate change impacts known and predicted. This is developed by SNTool, and BREEAM C, and addressed by Levels, and SDGs. Therefore, this indicator is recognized as a key social dimension of sustainability concern. This indicator is not promoted by SBTool^{PT} Urban, so it is considered not applicable to the CIM calculation analysis in this study. Nevertheless, further research can be conducted once the benchmarks and calculation methods are established.

3.2.33. The Indicator to Measure Proximity to Services

This indicator promotes recommendations to ensure residents have access to a range of services close to their homes. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by ISO 37120, and the SDGs. Therefore, this indicator is recognized as critical social dimension of sustainability concern. In the SBTool^{PT} Urban Guide, this indicator is calculated according to the number of available services and their respective distances to the residential zone. The results of the study indicate that this criterion can be calculated using the CIM model. Firstly, the type of services must be identified, and then the distances can be calculated using Dynamo.

3.2.34. The Indicator to Measure Recreational Facilities

This indicator promotes recommendations to ensure residents have access to a set of quality leisure amenities within walking distance of their homes. This is developed by SBTool^{PT} Urban, and LEED ND, and addressed by ISO 37120, and SDGs making it a prioritized social dimension of sustainability concern. The calculation methodology stated in the SBTool^{PT} Urban Guide is similar to the previous ones, while the use of the CIM model is applicable to calculate the indicator. The process of determining the recreational facilities begins with the identification of the facilities, and the remainder of the calculation follows the same procedure as the indicator for the Proximity of Services.

3.2.35. The Indicator to Measure Local Food Production

This indicator encourages recommendations to ensure city dwellers have access to fresh products, promote community food production and improve residents' nutrition, and support the economic development of the city/urban area. This is developed by SBTool^{PT} Urban, and LEED ND, and addressed by ISO 37120, and SDGs making it a prioritized social dimension of sustainability concern. According to the SBTool^{PT} Urban Guide, to calculate this indicator there are two parameters: Local Food Production Index and Community Garden Promotion Index. The first one is determined by the ratio of the total area destined for food production and the total number of inhabitants. To calculate this ratio using the CIM model, at first, the areas destined for food production must be identified, and then a Dynamo routine must be applied. The second parameter is evaluated through a verification checklist, but only two of the eight criteria can be assessed by the model. Thus, this indicator is classified as "NO", in terms of its applicability in CIM modeling.

3.2.36. The Indicator for Public Transport

In this indicator, recommendations are made to assess the public transport road network in terms of accessibility and quality, and to encourage the use of clean renewable energy resources for public transportation. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by ISO 37120, and the SDGs. Therefore, this indicator is recognized as a key social dimension of sustainability concern. Like the previous one, the SBTool^{PT} Urban Guide indicates two calculation parameters for this indicator: Public Transport Index and the Accessibility to Public Transport Index. Both are calculated through a verification list. To calculate the Public Transport Index using the model, it must be considered integration with another platform, like Google Maps. As one of the criteria in the Accessibility to Public Transport Index cannot be determined using the model, it is considered "PARTIALLY".

3.2.37. The Indicator to Measure Pedestrian Path Accessibility

This indicator promotes recommendations for mobility and pedestrian safety, the accessibility of people with reduced mobility, supports public health by encouraging utilitarian and recreational physical activity, and also encouraging the use of non-polluting means of transport. This indicator is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by ISO 37120, and the SDGs. Therefore, this indicator is recognized as a critical social dimension of sustainability concern. The SBTool^{PT} Urban Guide provides a verification list to calculate this indicator, but in general, the criteria cannot be calculated using the model, so the indicator is classified as "NO".

3.2.38. The Indicator to Measure Cycle Path Network

This indicator promotes recommendations for the quality cycle path network. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by ISO

37120. Therefore, this indicator is recognized as a crucial social dimension of sustainability concern. The SBTool^{PT} Urban Guide provides a verification list to calculate this indicator. Most of the criteria of the list can be calculated using the model, by characterizing and identifying the criteria and then applying a Dynamo routine. One of the criteria that cannot be assessed through the model is the Education and Awareness Program criterion. In this regard, the indicator is considered "PARTIALLY".

3.2.39. The Indicator to Measure the Usability of Public Transport for Physically Disabled Persons

This indicator promotes recommendations to provide an autonomous life and ensure equal mobility with others, for people with disabilities. This indicator is developed by SNTool, and addressed the SDGs, making it a priority concern for the social dimension of sustainability. This indicator is not promoted by SBTool^{PT} Urban, so it is considered not applicable to the CIM calculation analysis. In spite of this, a further study could be conducted once benchmarks and calculation methods have been determined.

3.2.40. The Indicator for On-Street and Indoor Car Parking Spaces

This indicator promotes recommendations for parking designs that adopt sustainable principles. It is developed by SNTool, and BREEAM C, making it a priority concern of the social dimension of sustainability. This indicator is not promoted by SBTool^{PT} Urban, so it is considered not applicable to CIM calculation analysis. However, when the benchmarks and calculation method are defined, a further study may be conducted.

3.2.41. The Indicator to Measure Access to Public Spaces

This indicator promotes recommendations for assessing the availability and quality of existing or planned public spaces. This is developed by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by ISO 37120, and the SDGs. Therefore, this indicator is recognized as a key social dimension of sustainability concern. The SBTool^{PT} Urban Guide establishes three calculation parameters for this indicator. The first one is the Percentage of Open Public Spaces, which is determined by the ratio of the Area of Open Public Spaces and the Total Intervention Area. To be calculated using the model, the open areas must be identified and characterized, then a Dynamo routine is applied. The second parameter is the Availability of Public Spaces per Habitant Index, which is calculated by the ratio of the Area of Open Public Spaces and the Total number of inhabitants. Like the previous parameter, the model can calculate this one. It is necessary to add information regarding the total number of inhabitants to the Dynamo routine. The last parameter, the Quality of Public Spaces Index, is determined from a verification list. By using the model, the criteria from the list could be added and assessed.

3.2.42. The Indicator for Valuing Heritage

This indicator promotes recommendations for the valorization of the heritage, which would promote the maintenance of the built and natural historical heritage of the place and encourage public use of it to ensure the heritage is preserved and strengthened for the future. This is developed by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by ISO 37120, and SDGs. Therefore, this indicator is recognized as a key social dimension of sustainability concern. This indicator is calculated in the SBTool^{PT} Urban Guide based on a verification list, however, it is not possible to use the model to assess the criteria listed in the checklist. Accordingly, the indicator is classified as "NO".

3.2.43. The Indicator to Measure Social Inclusion and Integration

This indicator encourages recommendations for social integration and inclusion, which aims to promote affordable housing for all people and promote local identity and a sense of community. This is developed by SBTool^{PT} Urban, SNTool, BREEAM C, and LEED ND, and addressed by ISO 37120, and SDGs. Therefore, this indicator is recognized as a key societal dimension of sustainability concern. According to the SBTool^{PT} Urban Guide, there are two parameters to determine this indicator. The first parameter is the Percentage of Houses for Integration and Social Inclusion, calculated based on the number of houses for social purposes, the number of houses for youth, and the number of total houses. It is possible to calculate this parameter using the model since the types of houses are identified, then a Dynamo routine is applied to calculate the parameter. The second parameter is the Community Participation Index, which is derived from a verification list. Accordingly, the model cannot be used to assess the criteria on the list; thus, the parameter is classified as "NO".

3.2.44. The Indicator to Measure Economic Viability

This indicator encourages recommendations to optimize the initial costs of an urban area based on the evaluation of operating and maintenance costs, during the operation phase (cost-effectiveness, economic feasibility). This is developed by SBTool^{PT} Urban, and LEED ND, and addressed by levels, and SDGs. Therefore, this indicator is recognized as a crucial concern of the social dimension of sustainability. This indicator is calculated in the SBTool^{PT} Urban Guide based on a verification checklist, which includes a Viability and Economic Plan. The plan cannot be assessed by the model, and the indicator is classified as "NO".

3.2.45. The Indicator to Measure Local Economy

This indicator encourages recommendations for supporting the local economy through the diversification of goods and services and enhancing internal circulation. This is developed by SBTool^{PT} Urban, BREEAM C, and LEED ND, and addressed by Levels, ISO 37120, and the SDGs. Therefore, this indicator is recognized as a key social dimension of sustainability concern. The SBTool^{PT} Urban Guide establishes two parameters to calculate it, the Diversity of Uses Index and the Local Economy Promotion Index. Both are calculated from a verification list. By identifying areas, analyzing them, and applying a Dynamo routine, the criteria for the Diversity of Uses Index can be determined. However, the second parameter, the Local Economy Promotion Index, is classified as "NO". This parameter is calculated based on an Economic Study, and like the previous indicator, cannot be derived from the model.

3.2.46. The Indicator to Measure Employability

This indicator promotes local employment, through the creation of jobs. This is developed only by SBTool^{PT} Urban, but addressed by ISO 37120, and the SDGs. Thus, this indicator is recognized as a critical concern in the context of sustainability. According to the SBTool^{PT} Urban Guide, this indicator is obtained from the ratio of the number of predicted jobs and the predicted population. Those criteria cannot be added and assessed by the model, so the indicator is classified as "NO".

3.2.47. The Indicator for Sustainable Buildings

The objective of this indicator is to promote sustainability at the building level by encouraging recommendations to reward sustainable building construction. SBTool^{PT} Urban, BREEAM C, and LEED ND have developed this indicator, and it is addressed by Levels and the SDGs. Hence, this indicator can be considered a priority concern of sustainability concern. A verification list is provided in the SBTool^{PT} Urban Guide for calculating this indicator. The model cannot be used to add or assess the criteria of the list.

3.2.48. The Indicator to Measure Environmental Management

This indicator promotes integrated environmental management from a Smart City perspective. It is developed by SBTool^{PT} Urban, SNTool, and BREEAM C, and addressed by ISO 37120 and the SDGs, making it a key concern of sustainability. As with the previous indicator, this one is calculated using a verification list in the SBTool^{PT} Urban Guide. The model cannot be used to add and assess the criteria of the list.

CIM has been found to be a viable method of calculating sustainability indicators and their parameters. In the case of this study, these calculations are based on the SBTool^{PT} Urban methodology. The analysis of sustainability indicators from SBTool^{PT} Urban, SNTool, BREEAM-C, and LEED ND has identified 48 indicators as priorities, of which 41 are presented in the SBTool^{PT} Urban methodology. These 41 indicators, presented by SBTool^{PT} Urban, have 52 calculation parameters, at least one parameter per indicator.

Evaluating how many indicators and their parameters can be calculated using CIM revealed that 28 parameters can be determined by a CIM model. In addition, seven can be partially calculated through CIM. The CIM model could not determine 17 parameters, and seven parameters were classified as "NON-APPLICABLE" since SBTool^{PT} Urban does not provide them. However, further research in this field may be able to assist in improving the calculations, and it is possible that additional parameters may be determined by the CIM. Table 1 summarizes the classification of indicators according to their possibility of assessment using CIM.

Table 1. Classification of indicators.

Prioritized Indicator	SBTool^{PT} U Indicator	Number of Parameters	Number of Parameters That Can Be Assessed by CIM		
			Yes	No	Partially
Passive solar planning	YES	1	1	0	0
Ventilation Potential	YES	1	1	0	0
Urban Network	YES	2	2	0	0
Use Natural Potential of Land	YES	1	1	0	0
Uses Density and Flexibility	YES	2	2	0	0
Reuse of Urban Land	YES	1	1	0	0
Building reuse	YES	1	1	0	0
Technical infrastructure	YES	1	1	0	0
Conservation of land *	NO	N/A	N/A	N/A	N/A
Distribution of green spaces	YES	1	1	0	0
Connectivity of green spaces	YES	1	1	0	0
Native vegetation	YES	1	1	0	0
Environmental monitoring Construction activity pollution prevention *	YES NO	1 N/A	0 N/A	1 N/A	0 N/A
Energy Efficiency	YES	1	0	0	1
Renewable energies	YES	1	1	0	0
Centralized energy management District heating and cooling *	YES NO	1 N/A	0 N/A	0 N/A	1 N/A
Efficient water consumption	YES	1	0	0	1
Effluent management	YES	2	1	1	0
Centralized management	YES	1	0	0	1
Low impact materials Energy embodied in construction materials *	YES NO	1 N/A	1 N/A	0 N/A	0 N/A
Construction and Demolition Waste	YES	2	1	1	0
Solid waste management	YES	1	0	1	0
Air quality	YES	1	0	1	0

Table 1. *Cont.*

Prioritized Indicator	SBTool^{PT} U Indicator	Number of Parameters	Number of Parameters That Can Be Assessed by CIM		
			Yes	No	Partially
Outdoor thermal comfort	YES	2	2	0	0
Acoustic pollution	YES	1	0	1	0
Light pollution	YES	1	0	1	0
Street safety	YES	1	0	1	0
Technological risks	YES	1	0	1	0
Adapting to climate change *	NO	N/A	N/A	N/A	N/A
Proximity to services	YES	1	1	0	0
Recreational facilities	YES	1	1	0	0
Local food production	YES	2	1	1	0
Public transport	YES	2	1	0	1
Usability of public transport for disabled people *	NO	N/A	N/A	N/A	N/A
Pedestrian path accessibility	YES	1	0	0	1
Cycle path network	YES	1	0	0	1
Car parking spaces *	NO	N/A	N/A	N/A	N/A
Access to Public Spaces	YES	3	3	0	0
Valuing heritage	YES	1	0	1	0
Social inclusion	YES	2	1	1	0
Economic viability	YES	1	0	1	0
Local economy	YES	2	1	1	0
Employability	YES	1	0	1	0
Sustainable buildings	YES	1	0	1	0
Environmental management	YES	1	0	1	0
TOTAL		52	28	17	7

* New indicators proposed by Salati et. al. [4]. N/A: Non-applicable.

3.3. Description of the Pilot Case Study

In order to demonstrate the calculation method proposed by this study, this subsection presents its applicability to one of the SBTool^{PT} Urban indicators. Indicator Distribution of Green Spaces was selected, and it aims to increase the availability of green spaces on sites. It is promoted by SBTool^{PT} Urban, and outlined in ISO 37120, and the SDGs, making it recognized as a prioritized environmental concern. To demonstrate and illustrate the calculation procedure, an urban area located in the Boavista Neighborhood, in Porto city, Portugal, was chosen. It is important to note that SBTool^{PT} Urban is a methodology adapted to the Portuguese context. Therefore, a Portuguese urban area was selected for the demonstration of the calculation method. Figure 3 shows the aerial view of the urban area.

The total area in the study corresponds to, approximately, 203,000 m^2. Which, approximately, 176,300 m^2 are built areas (e.g., building footprints, streets, sidewalks), and a total of 26,700 m^2 are considered green areas. The calculation methodology established by the SBTool^{PT} Guide is the ratio of the Total Green Area and the Total Area of the project. Therefore, the Percentage of Green Spaces is obtained, as shown in Equation (1):

$$P_{EV} = \frac{A_{EV}}{A_{IP}} \times 100\% \quad (1)$$

A_{EV} corresponds to the total green area (in this example, 26,700 m^2), and A_{IP} is the total area of the project (203,000 m^2, in this case). As a result, the Percentage of Green Spaces corresponds to 0.13.

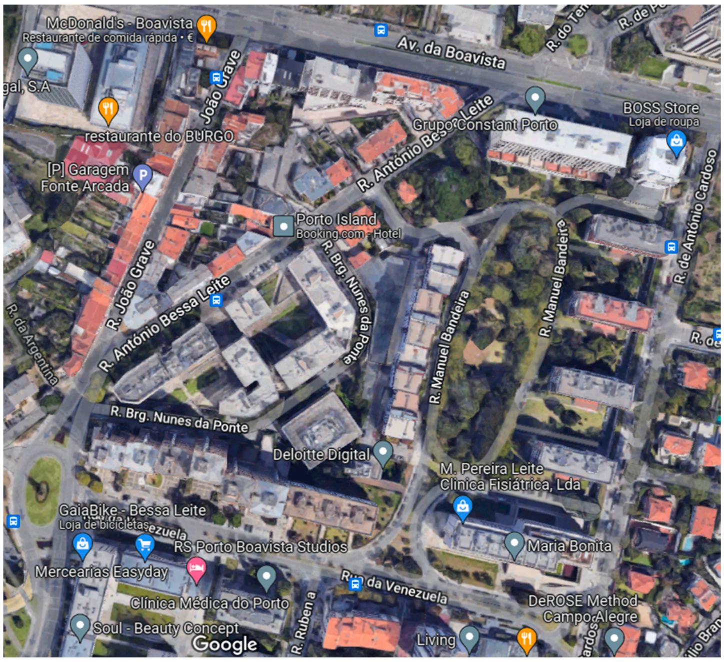

Figure 3. Aerial view of the chosen urban area—Boavista Neighborhood—Porto, Portugal.

To calculate this ratio through the proposed CIM platform, first, it is necessary to add the urban area to Revit. This can be done by using the online tool CADMAPPER. First, the area is selected, then a tridimensional map is created and added to the Revit model. Once the urban area is added to the Revit model, the second step is the characterization of the surfaces. This includes streets, sidewalks, green areas, and all the necessary information related to the indicator. After that, the parameters for calculating the indicator must be created using the Revit tool *shared parameters*. Taking into consideration that the indicator to be calculated is the Percentage of Green Areas, the *shared parameter* is named "*IsGreenArea*". Using the *shared parameter* created, all the green areas in the project must be characterized. Figure 4 illustrates the process in Revit, where the area marked in blue is the selected area to be characterized with the *shared parameter* "*IsGreenArea*".

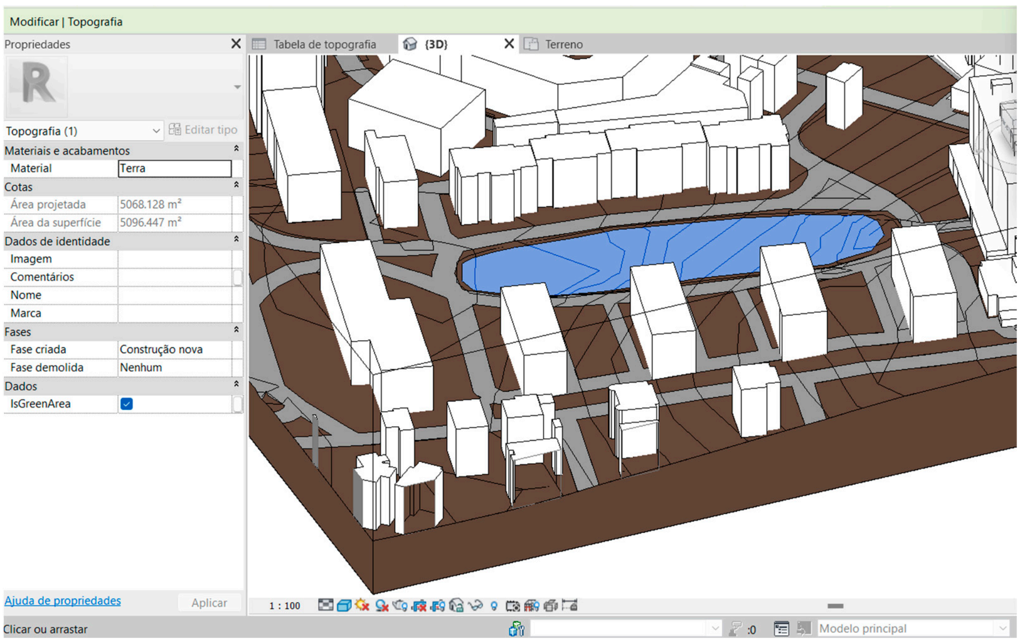

Figure 4. Selected areas in Revit and characterized according to the parameter "*IsGreenArea*".

The calculation process is then carried out by creating a Dynamo routine. Generally, programming will check all the areas in the model that are characterized as green areas using the shared parameter "*IsGreenArea*". The routine identifies the areas in the model and creates a list that will be the input of the calculation, Figure 5 illustrates this first phase of the routine.

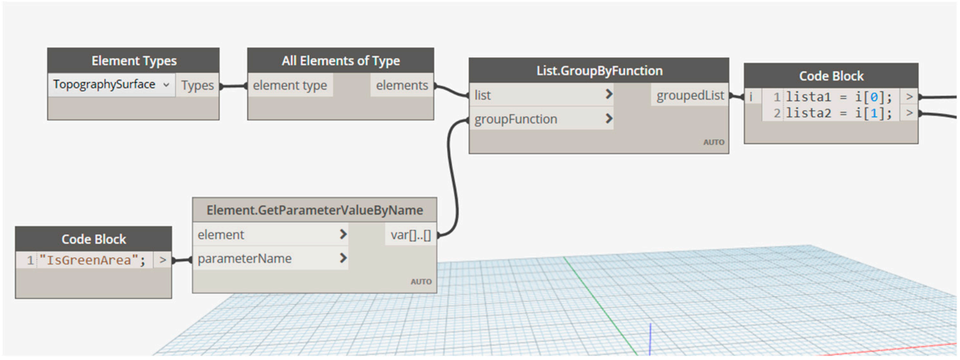

Figure 5. Information characterized into the Dynamo routine.

Then, using the inputs of the list (total area, total of green area, total of non-green area) the routine will calculate the ratio of the green areas and the total project area, and the result is the Percentage of Green Spaces, shown in Figure 6.

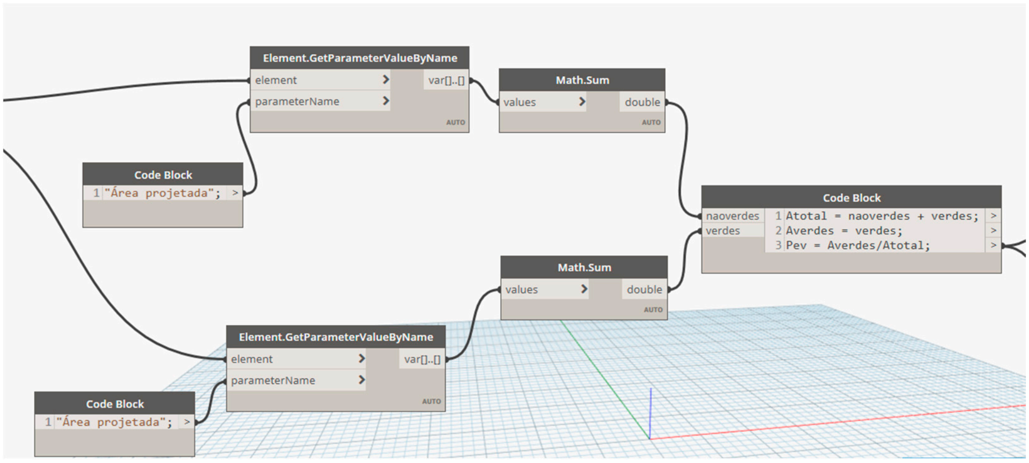

Figure 6. Areas characterized according to the parameter "*IsGreenArea*".

The result of the Percentage of Green Spaces obtained by the routine, shown in Figure 7 is 0.131449512397989, or simply 0.13, in accordance with the result presented before. According to SBTool^{PT} Urban, once the Percentage of Green Spaces has been calculated, the next steps are to apply benchmarks and normalize the data in order to obtain the classification. The value is converted into a qualitative scale where A+ represents the most sustainable, while E represents the least sustainable. As illustrated in Figure 7, Dynamo is capable of performing both processes, and the result is a "C" classification.

In this example, the application of CIM as a method of calculation has been demonstrated, along with the potential for its applicability. There are many advantages to this approach, but there are also some limitations. The ease and speed with which the calculations can be made are among the advantages. As well, this method may be useful for designers and urban planners when evaluating the sustainability of urban projects at an early stage. On the other hand, the first stage is a laborious process because it requires adding a significant amount of information to the model. It must be noted that the results of the Dynamo programming routine depend heavily on this stage. In addition, the size of the urban area is another limitation, large urban areas will require a high level of information to be incorporated into the model.

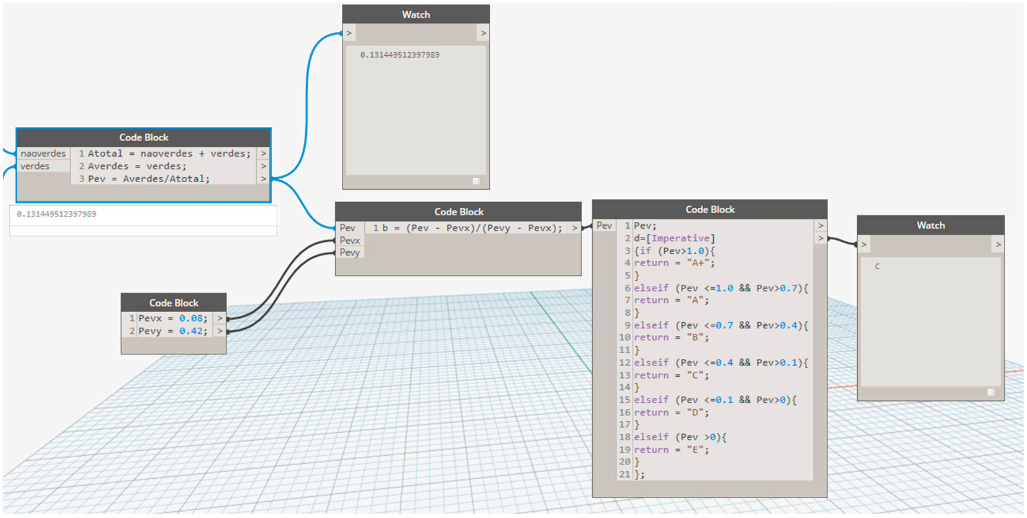

Figure 7. Benchmarks, normalization and qualitative scale.

4. Conclusions

As a result of the pursuit of urban sustainability, advances have been made in research on this topic, as well as the development of indicators and assessment systems. In the same way, information and communication technologies have been moving towards sustainable urban development, offering tools and systems that promote an increase in the efficiency of urban operations and help in the digital transition processes of cities, making them more 'intelligent' and sustainable. In line with this, City Information Modelling is an emerging concept that can help in the implementation of sustainability strategies in urban spaces. Furthermore, the CIM model can integrate the main city stakeholders, offering a multidisciplinary perspective, facilitating communication, and promoting the implementation of sustainable concepts.

Taking into consideration this perspective, this study analyzed some of the internationally well-known systems for the sustainability assessment of urban communities, focusing on identifying the prioritized established aspects and issues. This reveals that the strategies developed by SBTool^{PT} Urban are highly compatible with other well-known sustainability assessment methods, in terms of the comprised issues and aspects. Thus, the possibility of incorporating the most relevant indicators into the CIM concept for assessing urban sustainability has been identified. This analysis considered the Portuguese methodology SBTool^{PT} Urban as a baseline for calculation, and then evaluated the number of indicators that can be calculated using CIM.

The results indicate that CIM can be used to access urban sustainability, based on the identified prioritized indicators by the study. A total of 48 indicators are considered prioritized, where 41 of those indicators are promoted by the SBTool^{PT} Urban methodology. To calculate these indicators, the SBTool^{PT} Urban Guide established some calculation parameters. Therefore, there are 52 calculation parameters among the 41 indicators, and at least 28 parameters can be determined using a CIM model, and another 7 can be partially calculated. 17 parameters could not be determined by the CIM model, and seven parameters were classified as "NON-APPLICABLE" once they are not an SBTool^{PT} Urban indicator. In spite of this, further studies in this field may contribute to improving the calculations, and it is possible that the CIM may determine additional parameters.

By examining the application of the calculation method to one indicator, the method's main benefits and limits have been identified, including the potential for its applicability. The method provides the advantages of speed and ease of calculation, facilitating the implementation of sustainability assessment. Another advantage is the possibility of using it in the design stages since possible changes do not require extensive rework, but only re-application of the calculation routine. Design and urban planners, as well as promoters and industry businesses, can benefit from the use of CIM since sustainable strategies could be assessed in the early stages of development. In contrast, the initial stage of the project requires considerably more preparation than current calculation methods, because a large amount of information must be added to the digital models. This step is essential to achieve high-quality results when using Dynamo programming.

It is, however, necessary to conduct further research in order to calculate the newly proposed indicators. In this regard, CIM could be used as a tool to determine benchmarks and calculation methods. Considering that CIM is an emerging concept, novel approaches could be studied to integrate urban sustainability indicators into CIM. Furthermore, the CIM may be used to evaluate the indicators.

Thus, further studies are required to apply the proposed CIM method to all prioritized indicators. In this regard, a Revit template should be developed for the application of the calculation method.

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