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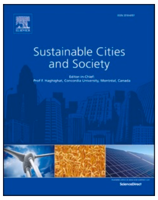

A novel framework to measure and promote smartness in neighborhoods

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ABSTRACT

Although several sustainability rating systems have been proposed to assess the sustainability performance of projects, there is still no comprehensive framework to support the implementation of smart solutions within buildings and neighborhoods.

To bridge this gap, this research project aims to propose an assessment framework to measure the smart readiness of neighborhood which can make a significant contribution in structuring and valuing existing potential technologies and smart solutions through various conceptual levels of smartness. This framework is developed using a mixed method approach through three phases: i) creating the taxonomy of smartening KPIs; ii) assigning weights to the KPIs by formulating determinant indexes reflecting sustainability and ESG targets (Customized based on four well-known certifications namely, LEED, BREEAM, DGNB, and GRESB); iii) introducing an output-based measurement method; finally, the framework is tested on a case study. The implementation of the smartening assessment framework through the different use of smart solutions and technologies resulted in a progressive sum of scores which emphasized the importance of stakeholders' engagement in planning smartening scenarios. This framework empowers managers and policymakers to clarify the objective level of smartness mostly through different social and environmental aspects and quantitatively distinguish the critical differences between smart and smarter neighborhoods.

1. Introduction

Although the concept of a smart city has been fundamentally established on the application of ICT-based technologies within building elements and city infrastructure, there are several research that have strived to incorporate human capital, social involvement, and environmental assets into this area. For many years, the smart city concept was defined based on a specific number of main cores such as smart government, smart environment, smart people, smart economy, and smart mobility (Carli et al., 2013). For the first time, Giffinger et al. (2007) proposed the concept of intelligent living, engaged with residents' quality of life, and developed a ranking model that assessed and compared strengths and weaknesses across smart European cities. In line with this trend, (Chondrogianni & Stephanedes, 2022) developed a decision-making model based on multifaceted parameters encompassing residents' demands and urban capacity for the incorporation of sustainability practices and smart solutions in urban spaces. Also, according to the European Commission (EC) report on Digital Cities Challenges, it is essential to align digital transformation strategies with the contextual characteristics of cities; this intention can be realized through various consultation practices with local actors and stakeholders who have been involved in the programming and implementation of digital smart solutions (European Commission, 2019). Another example is (IMD Business School, 2020) which introduced a smart city ranking report in which 109 cities were evaluated based on their residents' perceptions of two pillars pertinent to the technological services and existing infrastructure in their cities.

Although few smart city examinations have been proposed at the city scale, focusing on neighborhood-scale systems can provide valuable opportunities for urban planners and researchers to scrutinize this context. In addition, most recognized international sustainability assessment frameworks have been developed based on neighborhood scale protocols. Indeed, as a basic urban unit, the neighborhood is sufficiently small to test innovative planning and concepts and also large enough to include the socio-economic interactions of urban features and people needed to replicate the urban development model (Ferrari et al., 2022; Sala Benites et al., 2020; Sharifi et al., 2021). Assessing the smart city concepts that encompass the application of ICT technologies, at the

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neighborhood scale can more efficiently highlight substantial factors required to enhance desired capitals (Nakano & Washizu, 2021).

Despite a few efforts that have been made to measure the smartness of different contexts, the concept of smart measurement is still a fuzzy notion that cannot be restricted to a specific parameter and score due to the high rate of technological advancement. Providing tools to quantify the smartness of the cities has been prompted by raising questions such as how to make cities smarter or how to valorize the smartness of the cities and the neighborhoods (Serrano et al., 2022).

In general, using key performance indicators (KPIs) to examine the project's performance is a common method that brings transparent language for communicating and analyzing the potential benefits and drawbacks of the project (Albino et al., 2015; Dammann & Elle, 2006). There are several national and international sustainability rating tools that have been developed based on KPI-based methods, so far. Developing various KPIs to measure smartness is a challenging issue, which must not only consider the needs, concerns, and goals of different stakeholders but also be bound to the smart principles (Patrão et al., 2020; Abu-Rayash & Dincer, 2021). However, identifying and taking the required steps that culminate in developing a set of practical KPIs to address the smartness of cities or buildings is an emerging complex challenge. Consequently, no tool or practice has been presented to practically measure the smartness of cities, neighborhoods, or buildings (Carli et al., 2013).

An overview of existing smart assessment frameworks reveals the diversity of methods and procedures in measuring smartness, all associated with certain complexities. As an example, those smart- oriented KPIs that are based on the number of digital components across a project have never quantitatively justified the final benefits and impacts delivered to the project by the level of digital practices that have been made. In other words, there is very few research projects that specifically calculate the effects of using smart meters on energy reduction (OECD, 2020). For instance, to calculate the true impacts of automation and control measures on buildings' energy systems, (Apostolopoulos et al., 2022) measured the building's energy efficiency at each steps of retrofitting actions to distinguish and quantify the energy improvement results that can be achieved specifically by smart systems.

Some smart frameworks have also solidly focused on physical components of communication technologies such as sensors, cloud space, etc., so that it is hard to correlate them to the sustainability objectives. Another challenge in this field is urban regeneration activities which are individually or organizationally ingrained and managed by various stakeholders with multifaceted viewpoints and priorities in design and management processes. Lack of comprehensive technical knowledge around the significance and necessity of required activities- particularly on smart city topics that are novel and not well known- can exacerbate these potential conflicts and subsequently entangle project teams and policymakers with unstructured and complicated decisions that often lead to uncertain accomplishments (OECD, 2020; Prigogine & Stengers, 1997).

Along with these struggles and shortages in developing and implementing a comprehensive assessment framework, the application of the mixed-method approach has become more popular in recent years (Munda, 2008; Medda & Nijkamp, 2003). It is particularly useful in the projects that set of indicators and objectives are not clarified yet, and different entities are in compliance or in contradictory in making a decision about a set of public interests (Della Spina et al., 2017). This method outperforms the conventional limitations of single methods by inclusively taking into account the diverse perspectives of stakeholders and communities across multiple dimensions (Allmendinger & Haughton, 2009; Carlsson-Kanyama et al., 2008). The mixed-method approach supports the framework's development through different quantitative and qualitative steps. Despite several sustainability rating tools, there are still no quantitative measurement methods in the context of smart city assessment.

In order to address this gap, this research aims to use a mixed method approach to present a comprehensive assessment framework to measure the level of smartness of the neighborhood which can be used also as guideline for the engineers and managers to regenerate non-smart territories into the smart ones. This novel assessment framework can make a significant contribution in the implementation of smartening practices within neighborhood-scale communities, which is well-known as the most practical unit for introducing a new urban development framework (Sharifi et al., 2021; Ferrari et al., 2022). Moreover, this research based all its assumptions on social housing case studies, managed by a single entity, to avoid common challenges that often lead to the failure of regeneration projects. The novelty of this research project is particularly embedded in three phases, in which, a comprehensive list of smart solutions leading to the sustainability improvements and can be applied in the neighborhood context is created; an unprecedented set of indexes that reflects the main goals of smartening, including autonomy, sustainability improvements, and sustainability and ESG correlation, is developed to assign weights to the smart KPIs; and a new checklist of smart technologies that are required to deliver the expected smart services are solidified. Consequently, this assessment framework is expected to not only present technical requirements for smartening various elements of the neighborhoods at different levels (that can be considered based on different conditions, such investment budgets) but also but also affords the opportunity to gauge and compare the degree of intelligence integrated into the pursuit of sustainability goals. The structure of this paper is as follows: Section 2 provides background for the weight assignment methods specifically used in well-known protocols and existing smart measurement methodologies; Section 3 is the methodology that explains the steps of this research in detail; Section 4 presents the result in which the final assessment framework is presented; Section 5 analyzed different scenarios to implement the framework on a case study. The sixth section is the conclusion which summarizes the outcome of this research.

2. Literature review

With the emergence of smart city concepts, there has been growing interest in developing intelligent systems and solutions (Al Dakheel et al., 2020). Such efforts to realize smart cities have led to a handful of studies that have proposed different methods to assess the smartness of cities and neighborhoods. This section is divided into three parts to better understand the complexity of this field. The first part evaluates the strategy methods obtained by existing sustainability protocols to assign weights to their indicators. The second part focuses on intrinsic differences between ever-presented types of smart measurement methods. The third part evaluates potential indexes discussed in the literature for measuring the intelligence and smartness of the systems.

2.1. Weight assignment strategies in preceding protocols

During the last two decades, several sustainability protocols have been proposed to measure projects' sustainability performance at different scales (Ferrari et al., 2022). Assigning weights to the subjective indicators is a critical and common factor among all successful sustainability protocols, highlighting the different priorities and significances given to the indicators by the framework. An ideal method for weighing each indicator is to intuitively examine the measurable effects and benefits that can be obtained such as CO_2 reduction, cost reduction, etc. However, this method can only be employed for one-dimensional tools, where all indicators affect a unique subject (e.g., environment), rather than real tools, where each indicator involves several subject (e.g., energy, water, waste) (Gu et al., 2006). Analyzing well-known sustainability tools, namely LEED, BREEAM, and DGNB (Ferrari et al., 2022), which are all oriented around a single goal of sustainability provision, shows an adaptation of various indexes and equations for assigning weights.

Reviewing the preliminary documents of Leadership in Energy and

Environmental Design (LEED) reveals that the weighting process is based on the association of individual indicators throughout seven impact categories, namely, green economy, community, material resources, biodiversity, water resources, human health, and climate change which are set out to incorporate social, economic, and environmental characteristics into the future building industry. Therefore, in the first step, all impact categories are weighted through a consensus-driven process and normalized to deliver a total of 100 %. In the next step, the weight of each indicator has been determined qualitatively and quantitatively based on the indicators' impact on selected impact factors through three indexes, namely, relative efficiency, duration, and controllability. The first index refers to the relevance and strength of their relationship determined by five qualitative modes. The second index is about the duration of the effect, which is measured in four modes, starting from 3 years to +30 years. The last index is based on the level of dependency on responsible agents or sectors, which means that the expected performance of the indicator should be independent of the humans or entities' actions or decisions (USGBC, 2013).

Unlike the LEED system, which assigned weights to the indicators, the Building Research Establishment Environmental Assessment Method (BREEAM) system assigns weights to the categories. In BREEAM, the weighting matrix is based on three indexes but has a more straightforward form. The first step of assigning weights is to define the goals and scales of categories, which have been clarified through simple questionaries. The second part is the main step, in which all indicators have been gauged under three sustainability pillars of social, economic, and environmental disciplines, with respect to the three indexes namely, relevant to each pillar, the seriousness of the failure to address the goal respecting each pillar, and the potential improvement that the category's actions can bring to each pillar. All cells of this matrix have been filled by experts and the engineers of Building Research Establishment (BRE) based on a qualitative term, furtherly referred to the predefined five-point scale from 1 to 3, with interval of 0.5. There is also an option of zero point to show the complete irrelevance of each category to the corresponding dimension (Taylor & Ward, 2016).

In the German Sustainable Building Council or Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) system, evidence shows that the indicator weighting process is based on two major groups of importance of fields and time/ territorial frame which subsequently broke down into five indexes (DGNB, 2020). However, despite the wide application of this protocol across Europe, DGNB group have not released any official document to support the logic behind the weight assignment procedure in detail and it is not clear how the KPIs have been prioritized in this protocol.

Apart from sustainability perspectives, there are various protocols proposed to evaluate the corporation's impact on environment, social, and governance (ESG) pillars. Also, these protocols have used indicator-based evaluation methods in which all indicators are weighted based on predefined indexes. An example of these protocols is the well-known system of GRESB, in which weighting process is based on the level of relevance to each pillar of ESG, so that by answering a couple of predefined questions based on selected answers, the relevance will be dedicated to each issue and will be calculated to result in the final score. In GRESB, the weighing process is based on the level of relevance to every three pillars of ESG so that a set of predefined questions and answers reveals how much indicator is related to different issues covered by each pillar. Indeed, the final score of each indicator is similarly evaluated separately first by qualitative points, furtherly translated to the numerical values (GRESB, 2022).

Assessing a wide variety of sustainability rating systems clarifies that assigning weights to the categories (e.g., energy performance, water distribution) or to KPIs is mainly based on different types of indexes that can reflect the main goals and concerns of their institutional developers (Gu et al., 2006).

2.2. Smart measurement methods

Generally, most indicators in sustainability assessment tools are based on outcome values, so that the final performance of each system is the main objective to be examined. Hence, it is not far-fetched to say that the main differences between sustainability protocols are laid on the criteria selection, weights of importance, measurement scale, and thresholds (Gu et al., 2006). However, a deep investigation of previous studies demonstrate that there are also other procedures to examine the performance of projects which can be classified in three types: i) input-based (e.g., amount of investment, human resources); ii) output-based (e.g., number of sensors, data frequency); iii) outcome- based (e.g., energy saving, time needed to find parking slots) (OECD, 2020). Accordingly, input-based measurement indicators often quantify the amount of resources allocated to the specific policies or goals in the project and it is not important how these resources are spent or how effective the goal is addressed. Output based indicators refer to the devices and equipment that are established to achieve a specific goal or policy; while they don't often provide any procedure to follow up the final performance and check if the policy is well implemented or not; an evaluation of these indicators is based on units of measurement, such as the number of smart sensors, kilometers of bicycle path, availability of specific services and so on. Outcome based criteria examine the effectiveness of a policy and improvement actions; values obtained in these indicators are actually considered as the main motivation of the policy; however, as they can be easily affected by different inputs or measures, understanding the real effect of desired activities is not possible (Serrano et al., 2022).

As it was mentioned, there are a handful of studies that have proposed a framework for measuring the smartness of neighborhood elements. (Serrano et al., 2022) claimed that smart cities cannot be merely investigated through the number of technologies or deployment of novel devices without considering the final benefits delivered to the project. Instead, it is more practical to consider outcome- based criteria such as enhanced service delivery, reduced operating costs, increased commerce, and economic growth, promoted environmental sustainability, and quality of life. In this research, holistic KPIs were developed within three interactive levels, namely, technology analysis that includes sensors, actuators, network, data system, etc.), service and infrastructure (e.g., transportation, energy, water, building sectors, etc.), and benefits and application (e.g., job growth, health care, environmental quality, safety, etc.).

(Carli et al., 2013) measured the smartness of cities based on two categories of subjective and objective criteria. The subjective ones encompassed the physical elements of the city, such as infrastructure, urban assets, and quality condition, all of which can be analyzed within different criteria such as transportation demand, air quality, job opportunities, and green area. The method adopted to analyze and quantify these criteria was outcome-based metrics (e.g., percentage of green vehicles in relation to the total ones or the amount of CO_2 reduction). The second category includes intangible criteria that are more focused on residents' satisfaction, such as quality of medical services, transparency of bureaucracy, satisfaction with housing condition. Indeed, the second category helps the first category to be fulfilled and managed in a more complete way. (OECD, 2020) also proposed a smart city measurement framework based on the concepts defined by Organization for Economic Co-operation and Development (OECD) which revolve around the following three pillars: i) input and output based indicators that include the digital innovations that can be applied at city scale (e.g., mobility, jobs and firms, safety); ii) input-based indicators related to the stakeholders' participation in various construction phases and urban flows that were developed in dimensions such as capacity information, inclusiveness, equity, adaptiveness, etc. iii) Outcome- based indicators related to the final goal and policies of digitalization such as access to the services, quality of education, etc.

Besides, there is a group of studies that evaluate smart performance of neighborhoods or cities, by focusing on social criteria (e.g., health and key concerns). This group of studies often performs a questionnaire among residents and stakeholders to collect information upon their viewpoints around the quality of elements in their surrounding environment (Oh, 2020; Lytras & Visvizi, 2018).

To sum up, although the sustainability assessment methodologies have been commonly adopted as an output-based method, there is no unique measurement method for assessing the smartening concept, due to the different nature of KPIs considered in this context.

2.3. Indexes to weight smartness

Weighing the criteria for evaluating the smartness of a city or a region has been one of the challenging aspects that has always been ignored. The ability to measure the smartness of elements in urban activities goes beyond satisfying an intellectual curiosity. Without having a tool to measure and numerically compare the importance of intelligence in different fields, it is difficult to do and gauge the progress of the project. Accordingly, (NIST, 2000) testified that a good and complete understanding of any matter is only realized when it can be quantified and presented in numbers. In light of this trend, (Serrano et al., 2022) allocated weights to the smart criteria by employing five indexes, to wit, alignment of technology with community priorities, alignment of investment with community priorities, investment efficiency, information flow density, and quality of services, all of which finally determined for each indicator and case study through a questionnaire. In the context of smart systems, different indexes have been raised to evaluate the level of autonomy of the solutions. Scientifically speaking, autonomy is often known as one of the first characteristic of intelligent systems (Yavnai, 2001). Despite a widespread application of intelligent control and intelligent system, there is still no decisive definition about that and subsequently there is no consensus on its measurement methods (Evans & Messina, 2001). A performance assessment of intelligent systems necessitates answering a series of questions such as whether only the external behavior should be considered, or can the system be decomposed into smaller details? Whether they should be analyzed by generic parameter or subjective parameters? Whether mechanical capabilities should be factored from control capabilities, or not (Evans & Messina, 2001)?

(Yavnai, 2001) proposed two common methods for defining autonomy. The first method defined autonomy based on assigning responsibilities and ability to make decisions and self- control from a higher supervisor to a system or agent. In the second method, although autonomy is defined based on the fulfillment of the goals and responsibilities given to the system, it operated in an uncertain dynamic environment in which there is no or very little human or external agent intervention. Having simplified the architecture of intelligent systems into a set of features (e.g., learning process, experiencing, actions, etc.), (NIST, 2000) defined intelligent system as a structured system with autonomy, which has a body and a mind like a human. (Albus, 1991) defined intelligence as the ability of the system to perform the appropriate behavior in an uncertain environment, so that its appropriate behavior increases the probability of success in reaching the predefined goals. Intelligent systems can have different conditions in terms of appropriateness, which culminates in different degrees of success that can be achieved. In this regard, different concepts have been suggested for intelligence measurement. (NIST, 2000) alleged that measuring intelligence can be simplified to measuring the success of systems functions. He also raised the idea of measuring intelligence based on diversity of purposes, so that by increasing the number of functions, the level of intelligence increases. It should also be highlighted that doing an autonomous task may have different value for different types of people. Highlighting the idea that autonomy in systems should not be pursued solely for the sake of achieving autonomy (Antsaklis, 2020), emphasized the importance of addressing specific goals under uncertain conditions in the dynamic environment and system. This definition is similar to the term of optimization, which is always defined with respect to something, such as optimization of building energy performance in terms of reducing consumption. Just as the proposition of “this solution is optimal” is not comprehensible without clarifying the respected parameter, talking about the autonomy of a system without clarifying the goal and uncertainties is meaningless. Indeed, uncertainties limit the set of solutions and policies that help to achieve the goal. Consequently, if the system, under a set of uncertainties, can achieve the goal specified for it by itself, it can be called autonomous. Human intervention is often considered as one of the uncertain factors of autonomous systems so that, the more need for external interventions, the less autonomous is the system. The degree of autonomy is also a function of measuring the set of goals set out to be achieved and the number of uncertainties in the system and environment (Antsaklis & Rahnama, 2018).

It is not far-fetched to say that the relationship between levels of human intervention, uncertainties, and level of autonomy is complicated and depends on multiple factors. There are two viewpoints upon the relationship between system’s autonomy and human intervention (Beer et al., 2014). The first group of scholars believed that high autonomous systems should be mostly independent of any human intervention (Huang et al., 2004; Huang et al., 2005). All frameworks developed based on this idea have considered a negative correlation between levels of autonomy and all sorts of human interaction. However, the second group of researchers proposed the idea that the higher level of autonomy require more level of human interaction with the system (Thrun, 2004; Goodrich & Schultz, 2008). They often believed that the ability to make decisions and interact with humans required a higher level of autonomy.

Indeed, the main difference between these two perspectives is due to scope of boundary and type of autonomy that is expected by the smart systems. The proposition of “higher uncertainties in a system can led to a higher level of autonomy” is only reliable when the system is able to make decisions and respond to changing circumstances without human intervention. For example, in some multi-steps processes (e.g., waste management), if the system is not capable of handling the situation on its own, a higher level of uncertainty may also result in a higher need for human intervention. To accurately measure the level of autonomy in a smart system, a range of factors, including the system’s decision-making processes, its ability to operate independently, and the degree to which it relies on human input, is required to be considered.

To sum up, there are variety of indexes and measurement methods that have been considered in assessment frameworks. In this regard, for developing a novel methodology it is essential to accurately analyze and select the appropriate procedure based on the nature of KPIs and purposes that are adopted for the framework.

3. Methodology

This section explores all the steps required to develop a novel assessment framework, that enables stakeholders and policy makers to measure neighborhoods’ level of smartness and obtain information for their potential smartification. To develop every quantitative and qualitative step, a mixed method approach is used. The mixed method approaches have been widely used in the field of framework development, urban planning, and regeneration projects to make a concrete structure for clarifying the problems and identifying the objectives. In detail, this systematic procedure formulates all influencing phases of the framework and allows the outcomes of each step to be considered as inputs for the next subsequent phase (Creswell & Creswell, 2017). As demonstrated in Fig. 1, in this research, the mixed method approach is developed based on three phases, which are furtherly explicated in the following subsections.

3.1. Phase 1. Developing taxonomy of smart KPIs

The initial phase of this methodology concentrates on taxonomy of

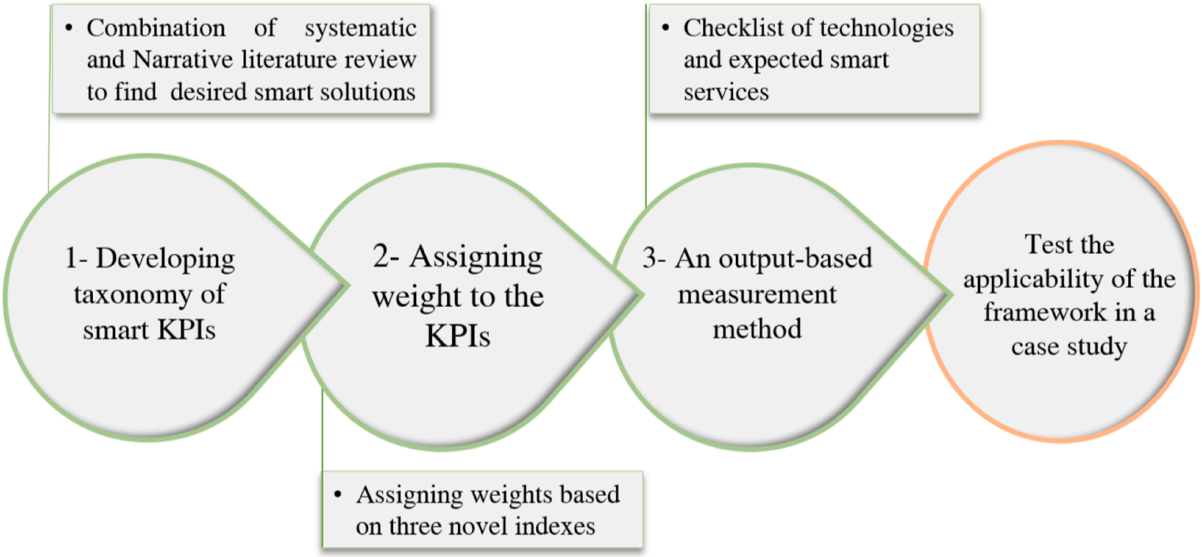


Fig. 1. Three phases of mixed- method approach and final step of testing on a case study.

smart solutions, progressed through a few steps and already presented in Ferrari et al. (2023). The searching process to create the list of smartening KPIs begins with selecting those urban issues (e.g., water, waste, energy) that can be covered and relatively supported at the neighborhood scale project. For instance, even though many sustainability protocols prioritize economic or mobility concerns, these issues cannot be incorporated in the context of residential neighborhood. In the next part, all smart solutions and novel technologies which have been elaborated in reliable sources (i.e., international guidelines, EU projects in cordis, Scopus, etc.) are collected. To this end, a combination of systematic and narrative literature review conducted to find out and examine potential answers to the thematically differentiated research question of “Which, how, and to what extent smart solutions can improve sustainability of specific domain?”. Consequently, 19 smartening KPIs, categorized under six categories of building energy systems, renewable energy supply, water distribution system, waste management, social wellbeing, and outdoor spaces, are considered to proceed in this assessment framework.

3.2. Phase 2. Assigning weights to the KPIs

As discussed in Section 00, weight assignment is a critical part of each assessment framework which is formulated based on specific indexes aiming to reflect its main objectives. According to the literature, the main goals of smart solutions can be summarized in two significant objectives: i) improving the performance of systems in the neighborhood or buildings; ii) reducing the required human interventions and uncertainties which almost culminates in the better operation of the system. Therefore, these two factors can play an important role in discriminating the priorities among an implementation smart solution. However, there is another factor that must be taken into account, which is the intrinsic difference in the significance of indicators’ nature across different regions and societies. For instance, the priority to improve energy, water, and waste-related issues varied among different regions. As mentioned in Ferrari et al. (2022), this aspect have been also the main motivation for the development of numerous sustainability protocols. To reflect this aspect, this research takes advantage of sustainability and ESG protocols that have been already well established consistently across various industries and communities to define the third index of weight assignment. To this end, the subjective affinity of smart KPIs with the sustainability indicators within different protocols has been evaluated. For this research, this affinity is investigated through four well-known ESG and sustainability protocols, namely LEED, BREEAM, DGNB, and GRESB. This enables users to prioritize the implementation of smart solutions based on their desired version of protocols. This variation within the weights of smart KPIs ensures that these values are tailored to the unique context of each situation. Indeed, the good establishment of these sustainability protocols allows users to choose the certification that aligns with their specific region’s specifications or industry’s trends. At the end, Eq. (1), is considered to assign weights of importance to the smart KPIs, based on the logic behind the indexes.

$$W_i = H \times (1 + P) \times A_i \tag{1}$$

where, W_i refers to the weight of i^{th} smart indicator, H is the human intervention’s coefficient, P refers to the average range of improvement that smart solution can bring to the system, and A_i refers to the affinity of smart solution to the corresponding sustainability indicator in different protocols.

As mentioned in the literature, the more human interaction is required to accomplish the work, the more likelihood of performance failure. The following coefficient is somehow considered also in LEED certification, as the controllability on indicators (USGBC, 2013). In this regard, H coefficient is classified in 5 levels: i) passive human which means the fully automated system: 1, the need for entities intervention: 0.75, the need for residents and entities intervention: 0.5, the need for residents’ intervention: 0.25, and finally, the system without any automation strategy: 0.

Coefficient P, referred to the average improvement resulted through the application of smart solutions. To this end, all similar studies and projects that use similar smart solutions and achieve a specific range of improvement have been considered. It is worth noting the enhancements may be applied on different subjects, while its consideration as a percentage makes it possible to compare them in the same unit. By the same token, the coefficient P is achieved from the average values of the improving percentages, collected and presented in Ferrari et al. (2023).

Finally, coefficient A_i, which elaborate on the affinity between smart solutions and sustainability or ESG scores is conducted based on four sustainability protocols of LEED, BREEAM, DGNB, and GRESB. After calculating the ranges of protocols’ scores that can be covered by existing smart KPIs, they are normalized in each protocol to deliver the full score of 100. It is worth noting that each sustainability protocol is investigated within both buildings and neighborhood scales.

3.3. Phase 3. An output-based measurement method

The third phase of this methodology aims to propose a novel modified- method compared to the existing ones that have been discussed in Section 2.2, to measure the level of smartness in a single KPI. As mentioned in previous sections, smart measurement methods, technically can be classified in three types of input-based, output-based, and outcome-based. All three methods are inevitably accompanied by some pros and cons. In the first two methods, the final effect of the systems cannot be followed and inspected, and also in outcome-based, as they don't report the system's configurations and technical details, it is not possible to see whether these improvements are obtained from the smart systems or other non-smart improvements (e.g., insulation of walls for measuring energy improvement).

Due to main purpose of this research, measuring the smartness, a modified output-based method focusing on the proportion and the availability of expected technologies to provide smart services have been adopted to examine the level of smartness in each indicator. As mentioned earlier, this method is different from sustainability assessment procedures which are based on the final values of the performance of services (outcome based). In light of this trend, (Becker et al., 2017) also testified that smart indicators are mostly engaged with the different extent of innovation, human interventions, and implementation that may include the short-term and mid-term fulfillment of the desired objectives, while sustainable indicators are more dealing with the long-term impacts of measurements (Dall & Bruni, 2020).

Since the concrete number of smart devices and operations are the function of neighborhood's characteristics and scales, this research attempts to gauge smart performance of project, based on percentage of coverage and smart readiness levels. To this end, an Excel-based checklist is provided involving the required types of sensors, control systems, actuators, special software, and any other necessary components that should be embedded for delivering expected smart services at five levels of smartness.

Along with SRI technical reports (Verbeke et al., 2020), in which all indicators have been developed based on multifarious smart readiness and functionality levels, in this phase, technologies required to satisfy the smartness of each indicator are elaborated through five levels. These five levels, conveniently presented in a checkbox list which empower users to select the types of technologies that are embedded in each component of indicators. These levels have been designed based on the following principles:

- Level -1: Non-Automated, manual operation, no connectivity
- Level 0: Basic automation features- simple preset functions, Basic monitoring and control, basic communication
- Level 1: Enhanced Automation- advanced automation, programmable settings, Advanced monitoring, control, and feedback,
- Level 2: Smart Automation- high level of smartness and automation, intelligent algorithms, machine learning, Enhanced monitoring, control, optimization, Integration with other systems and remote control
- Level 3: Advanced Smart Automation- advanced AI capabilities and self-learning algorithms, exhibits sophisticated monitoring, control, and optimization, Integration with multiple systems, cloud-based services, and advanced connectivity options.

Once users have selected the type of technologies embedded in each component of the indicators, the level of smartness will be automatically calculated based on the average levels of its components' smartness. In some indicators there are also other optional components to be considered, which must be determined by users at the beginning of each sheet, though Yes/No questions. In the case of inclusion of optional components, the final level would also encompass these selected components in the calculation process. After filling the checklist of available technologies, users are obligated to propose required documents testifying the availability of selected technologies and services to be verified (like the existing protocols). In addition, users need to specify the percentage of the dwellings or the neighborhood elements that are covered (Cov_i) with these smart solutions. The level of smartness within each indicator, can be measured based on the following equation:

$$LoSi_i = LoSc_i \times Cov_i \tag{2}$$

where, $LoSi_i$ refers to the weightless level of smartness of each indicator, $LoSc_i$ is the final level of smartness of components, ranged between 0 and 1 through 5 levels, and Cov_i is the percentage of coverage that smart solutions are incorporated. In the final step, users can select the sustainability certification desired to satisfy, which will automatically update the weights of importance for each indicator, as discussed in previous subsection. Consequently, the smartness of the neighborhood, can be assessed through the Eq. (3):

$$\text{Smartness of neighborhood score} = \sum \left(LoSi_i \times W_i \right) \tag{3}$$

As all values through this process are normalized, the final score of smartness of neighborhood is represented out of 100.

4. Results and discussion

The following subsections represents the results of each phase in a similar order:

4.1. Taxonomy of smart KPIs

As technology continues to advance towards digitalization and becoming smart, more daily activities are being affected by computer tools and smart devices. These advancements have caused a significant shift towards more automated and connected ways of living and increased the dependency between humans and technologies (Balogun et al., 2020). In light of this trend, (Macht, 2016) alleged that, by the year 2030, more than 50 billion devices will be connected to the IoT network and about 52 % of users use smart and digital systems to improve their activities. Although the complete value of data flowing between these smart urban elements has not been fully realized yet, they are considered a cornerstone for a transition toward the true development of the smart and efficient city (Mondejar et al., 2021). Technically, when smart and intelligent tools aimed at meeting sustainable objectives, it can be incorporated in the domains of smart sustainability or digital sustainability; and therefore, an inclusive program intended to introduce the application of these tools must cover all committed elements (i.e., in terms of sustainability or ESG goals), such as economic, environment, social, cultural norms, and even spiritual values. In this research, the term "smart" has been focused to describe traits like intelligence, self-control, and system adaptability. Thus, in the following subsection, only those systems that have the capacity to reduce the need for human intervention on adjustment of systems or offer smart services that enable citizens to behave more intelligently are deemed to be actual "smart". Based on (Ferrari et al., 2023), which is the preliminary stage of this project on developing an smart assessment framework, all smart solutions are structured as 19 KPIs classified under 6 categories, illustrated in Fig. 2. All details regarding this set of indicators are comprehensively investigated in this research.

4.2. Weights of importance on smartening KPIs

As mentioned in the methodology section, this research determines three indexes, including percentage of improvement, level of human intervention, and sustainability affinity, to assign weights to the predefined smart sustainable KPIs. This process involved the customization of the third index that covers four well-established protocols (i.e., both at building and neighborhood scales) to reflect the inherent significance of each indicator in different contexts. By doing so, stakeholders who are

Fig. 2. Classification of applicable smart solutions in neighborhoods.

prone to achieve a specific certification can use the relevant version of the smart framework from which the points are derived. The final weight of each indicator is quantified based on Eq. (1) that deals with all these selected indexes. Table 1 presents the final sets of KPIs scores respecting different sustainability and ESG protocols, normalizing out of 100 scores.

Respecting the coefficient *H*, in systems where smart solutions mitigate or even eliminate human intervention (e.g., smart HVAC system, smart lighting system.), this index is equal to one. For instance, smart HVAC system controls the indoor environment conditions based on just the amount set points designated by the user to the system; and it eliminates the need for users' action. In other words, the level of certainty in achieving the final goal of these systems will not be affected by human intervention or human error. While there are some KPIs (e.g., smart waste management, smart community engagement) that are inevitably function of entity or/and residents' intervention.

For instance, despite the provision of smart bins in the neighborhood, its final achievement always depends on the level of residents' accuracy in waste separation and using colored plastic and waste collector trucks to be equipped with GPS system and communication system connected to the smart bins sensors. This dependency on human actions reduces the certainty of smart solutions to achieve their desired goal and subsequently their value to attract investment. Subsequently this trend is applied to all KPIs.

Respecting the average percentages of improvement, all potential percentages are assigned based on the ranges that have been concluded in similar smart systems and projects, some of which mentioned in Ferrari et al. (2023). Due to the inherent diversity of the KPIs, it is clear that the amount of improvement in each KPIs is discussed around different topics (e.g., reducing water consumption, reducing energy consumption, etc.). Even though, representing these values as percentages makes it possible to reflect the amount of improvement in each system compared to their non-intelligent options.

Regarding the index of affinity with sustainability protocols, after matching each KPI to its respective sustainability indicators, the points are summed up and normalized out of 100. Analyzing the affinity with different protocols shows that this smart framework can averagely cover 62 % of LEED certification scores (64 % per neighborhood and 60 % on building scales). While this amount in the BREEAM and DGNB, certifications are in average limited to 36 % and 26 %, respectively. This highlights the difference between the concentrations of indicators in these two certifications which is more focused on fundamental elements and actions that should be managed at higher administrative scales such as the improvement of mobility, economic, biodiversity, etc. In addition, assessing the coverage of collected smart solutions throughout the GRESB's indicators reveals that only 32 % of these solutions can be related to these ESG measures, which is due to the high number of indicators that are classified under government-based categories.

Table 1
The list of weighted smart KPIs across different sustainability and ESG protocols.

Categories	Smart KPIs	LEED-Building	LEED-Neighborhood	Average LEED	BREEAM-Building	BREEAM-Neighborhood	Average BREEAM	DGNB-Building	DGNB-Neighborhood	Average DGNB	GRESB
SMART Building automation technologies - (optimization of energy consumption)	1.1. HVAC system	25	11	18	26	10	18	39	16	27	16
	1.2. Water use in buildings	2	2	2	2	2	2	1	1	2	4
	1.3. Lighting system	10	2	6	6	11	8.5	9	2	5	7
	1.4. Buildings opening	14	2	8	11	10	10.5	4	2	3	6
	1.5. Electricity management system	2	2	2	3	2	2.5	0	2	1	2
	1.6. Maintenance and commissioning	12	1	6.5	5	14	9.5	12	10	11	5
RES generation and supply	2.1. Renewable energy grid	7	22	14.5	7	0	3.5	7	7	7	12
Smart water	3.1. Water distribution network	15	8	11.5	6	0	3	4	7	6	11
	3.3. Irrigation Control system	4	6	5	5	0	2.5	4	0	2	5
	3.4. Grey water reclamation	0	7	3.5	14	0	7	3	0	2	5
Smart waste management	4.1. Waste collection systems	0	8	4	3	0	1.5	0	7	4	7
	4.2. Organic waste composter	0	2	1	0	0	1	0	3	1	4
Smart Social welfare	5.1. Community engagement and awareness	1	12	6.5	1	12	6.5	3	10	6	7
	5.2. Community equity	0	5	2.5	0	7	3.5	3	9	6	3
	5.3. Security, safety, and health provision	0	0	1	2	4	3	1	2	2	1
Smart management of outdoor environment	6.1. Smart nearby public station	0	0	0	2	2	2	1	3	2	1
	6.2. Outdoor light	3	7	5	6	13	9.5	4	6	5	1
	6.3. Parking areas	1	1	1	0	2	1	3	7	5	1
	6.4. Garden management	2	2	2	0	10	5	1	6	3	2
Total		100	100	100	100	100	100	100	100	100	100

4.3. Measuring smartness through KPIs

This section elaborates on a series of checklists of technologies and smart functionalities that are required to drive a smart system in each indicator. In this measurement tool, each indicator is examined in a separate sheet of Excel that presents one or more columns of components that build up the whole control system of the indicator (Fig. 3). These components are further classified into five levels of functionality, each of which encompasses the potential components such sensors, control systems, actuators, special software, etc., required for each level. This comprehensive checklist takes into account the specific level of smartness in each component of indicators, by checking the availability of required technologies- shown as the item of checkboxes- which have been installed in the neighborhood context. These levels encompass various items, from basic elements (Level −1) to the more advanced technologies including AI integration, advanced meters, mobile applications, etc. (Level 3). It is not far-fetched to presume that only the last three levels (i.e., Level 1 to Level 3) are scored and certified as smart solutions.

Practically speaking, in each component of KPIs, users are required to select the checkboxes of technologies that are considered in their system to determine the levels of smartness of components (LoSc). After applying the technologies for all components, the measurement tool will automatically calculate and assign the indicators' LoSi, measured in the range of 0 to 1. It is worth noting that items of checklist should be addressed respectively from Level −1 to Level 3, and it is not possible to satisfy a level of smartness without addressing the previous ones. Fig. 3 shows a sample of checklist for smart HVAC system. Besides, the checklist of other KPIs is provided as a supplementary material.

As each KPI may be applied to a specific percentage of the neighborhood, or there will be some optional components to be considered, users are needed to complete some initial information at the beginning of each sheet. After completing all sheets of KPIs, the last step of this measurement tool is choosing the desired sustainability or ESG protocols to customize the weights of importance (i.e., obtained from Eq. (1)) which is supposed to be assigned to the KPIs (Fig. 4).

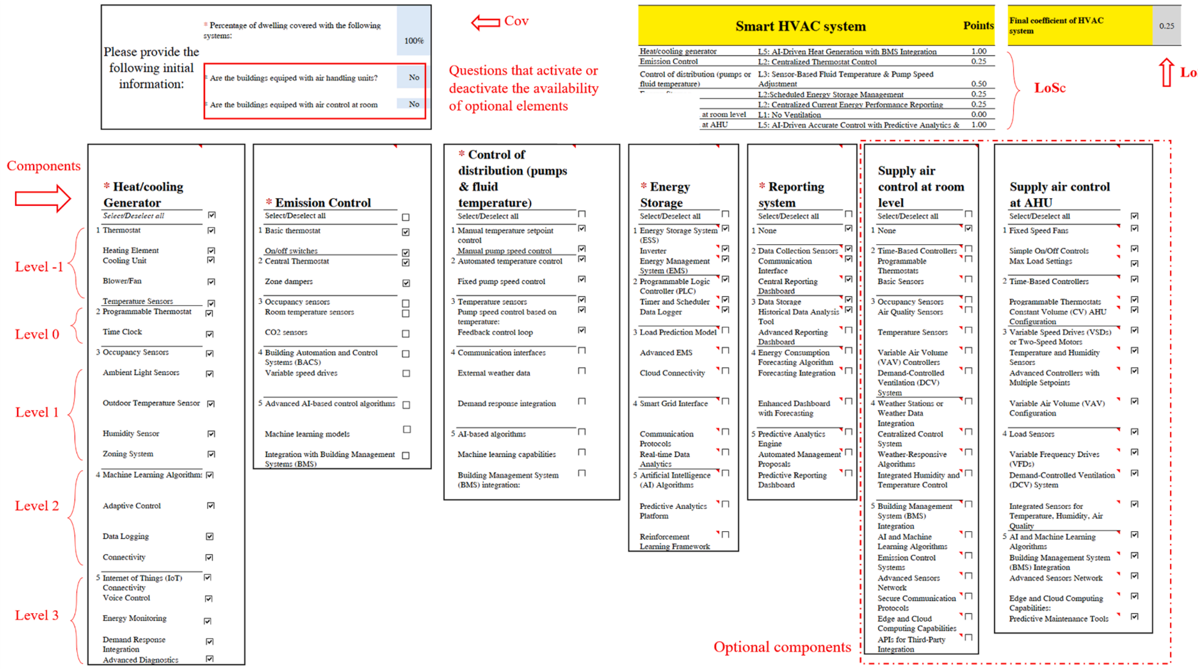
At the end, the final scores of smart assessment practices on different case studies can be evaluated within the range of certifications allocated based on maximum possible scores in each specific level of smartness. It is worth noting that there is no limitation on variation of levels of smartness among KPIs and their accumulation is a matter of fact to be reached to the desired level of certifications. Table 2, demonstrates the level of scores in each protocol that can reach a specific certification.

5. The assessment framework implementation

After finalizing the smart assessment framework, it has been tested through an implementation on an existing case study. In similar studies related to the regeneration framework, scenarios have been often formulated based on multifaceted aspects such as different usages, different investment levels, or depth of renovation activities. In this research, the theoretical implementation of the framework progresses within two steps. The first step is neighborhood auditing, which is generally considered as the base-run scenario of every regeneration project. The second step is developing two scenarios to test the implementation of various levels of smartness based on managers' and residents' priorities that have been collected through a seminar panel and a few numbers of questionaries.

5.1. Case study description

In this research, the selected case study is a social housing neighborhood managed by private society, which is not only responsible for delivering houses, but also providing services. The main reason motivating the selection of a social housing case study is that these communities are commonly managed by a unique entity, in which all regeneration measures and policies can be effectively realized without any additional managerial challenges. The selected society is a cooperative of inhabitants that has planned to provide its social body with a complete housing service which is not only a concrete answer to the need for its members' accommodation, but a series of services aimed at promoting and improving the well-being of its members. In overall, this cooperative is comprised of 17 residential neighborhoods. The case study is in the northern areas of Milan, Italy. This neighborhood was built in 1962 and experienced a few renovations over the years. As shown in Fig. 5, this neighborhood is composed of eight detached buildings accommodating 356 dwellings.



Please provide the following initial information:

* Percentage of dwelling covered with the following systems: 100%

* Are the buildings equiped with air handling units? No

* Are the buildings equiped with air control at room No

Smart HVAC system		Points
Heat/cooling generator	L5: AI-Driven Heat Generation with BMS Integration	1.00
Emission Control	L2: Centralized Thermostat Control	0.25
Control of distribution (pumps or fluid temperature)	L3: Sensor-Based Fluid Temperature & Pump Speed Adjustment	0.50
	L2:Scheduled Energy Storage Management	0.25
	L2: Centralized Current Energy Performance Reporting	0.25
at room level	L1: No Ventilation	0.00
at AHU	L5: AI-Driven Accurate Control with Predictive Analytics &	1.00

Final coefficient of HVAC system	0.25

*** Heat/cooling Generator**
Select/Deselect all ☑
1 Thermostat ☑
Heating Element ☑
Cooling Unit ☑
Blower/Fan ☑
Temperature Sensors ☑
2 Programmable Thermostat ☑
Time Clock ☑
3 Occupancy Sensors ☑
Ambient Light Sensors ☑
Outdoor Temperature Sensor ☑
Humidity Sensor ☑
Zoning System ☑
4 Machine Learning Algorithms ☑
Adaptive Control ☑
Data Logging ☑
Connectivity ☑
5 Internet of Things (IoT) Connectivity ☑
Voice Control ☑
Energy Monitoring ☑
Demand Response Integration ☑
Advanced Diagnostics ☑

*** Emission Control**
Select/Deselect all ☐
1 Basic thermostat ☑
On/off switches ☑
2 Central Thermostat ☑
Zone dampers ☑
3 Occupancy sensors ☐
Room temperature sensors ☐
CO2 sensors ☐
4 Building Automation and Control Systems (BACS) ☐
Variable speed drives ☐
5 Advanced AI-based control algorithms ☐
Machine learning models ☐
Integration with Building Management Systems (BMS) ☐

*** Control of distribution (pumps & fluid temperature)**
Select/Deselect all ☐
1 Manual temperature setpoint control ☑
Manual pump speed control ☑
2 Automated temperature control ☑
Fixed pump speed control ☑
3 Temperature sensors ☑
Pump speed control based on temperature: ☑
Feedback control loop ☑
4 Communication interfaces ☐
External weather data ☐
Demand response integration ☐
5 AI-based algorithms ☐
Machine learning capabilities ☐
Building Management System (BMS) integration: ☐

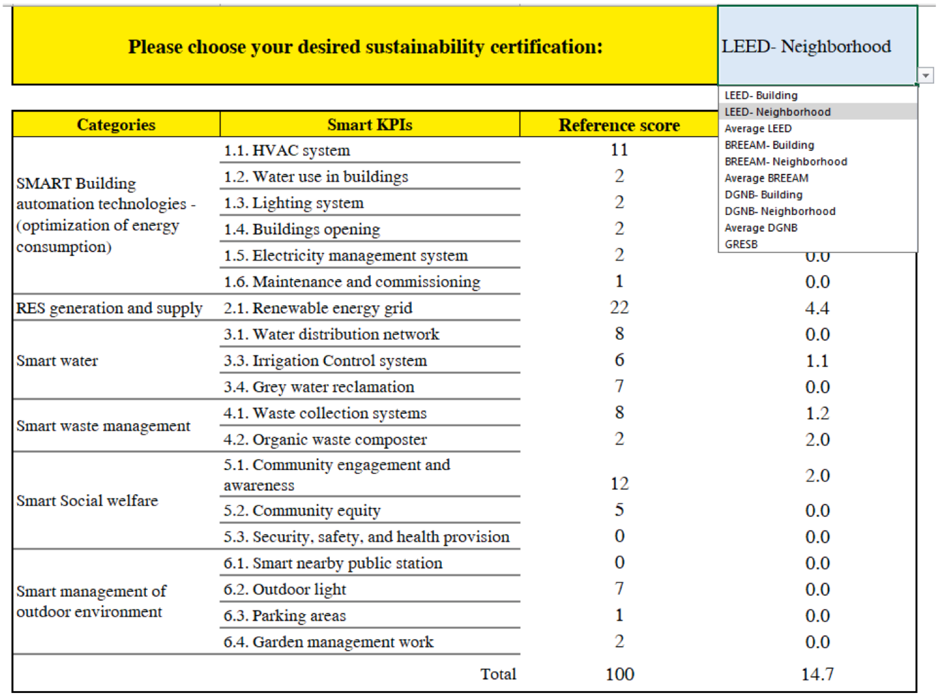
*** Energy Storage**
Select/Deselect all ☐
1 Energy Storage System (ESS) ☑
Inverter ☑
Energy Management System (EMS) ☑
2 Programmable Logic Controller (PLC) ☑
Timer and Scheduler ☑
Data Logger ☑
3 Load Prediction Model ☐
Advanced EMS ☐
Cloud Connectivity ☐
4 Smart Grid Interface ☐
Communication Protocols ☐
Real-time Data Analytics ☐
5 Artificial Intelligence (AI) Algorithms ☐
Predictive Analytics Platform ☐
Reinforcement Learning Framework ☐

*** Reporting system**
Select/Deselect all ☐
1 None ☑
2 Data Collection Sensors ☑
Communication Interface ☑
Central Reporting Dashboard ☑
3 Data Storage ☑
Historical Data Analysis Tool ☑
Advanced Reporting Dashboard ☐
4 Energy Consumption Forecasting Algorithm ☐
Forecasting Integration ☐
Enhanced Dashboard with Forecasting ☐
5 Predictive Analytics Engine ☐
Automated Management Proposals ☐
Predictive Reporting Dashboard ☐

Supply air control at room level
Select/Deselect all ☐
1 None ☑
2 Time-Based Controllers ☐
Programmable Thermostats ☐
Basic Sensors ☐
3 Occupancy Sensors ☐
Air Quality Sensors ☐
Temperature Sensors ☐
Variable Air Volume (VAV) Controllers ☐
Demand-Controlled Ventilation (DCV) System ☐
4 Weather Stations or Weather Data Integration ☐
Centralized Control System ☐
Weather-Responsive Algorithms ☐
Integrated Humidity and Temperature Control ☐
5 Building Management System (BMS) Integration ☐
AI and Machine Learning Algorithms ☐
Emission Control Systems ☐
Advanced Sensors Network ☐
Secure Communication Protocols ☐
Edge and Cloud Computing Capabilities ☐
APIs for Third-Party Integration ☐

Supply air control at AHU
Select/Deselect all ☑
1 Fixed Speed Fans ☑
Simple On/Off Controls ☑
Max Load Settings ☑
2 Time-Based Controllers ☑
Programmable Thermostats ☑
Constant Volume (CV) AHU Configuration ☑
3 Variable Speed Drives (VSDs) or Two-Speed Motors ☑
Temperature and Humidity Sensors ☑
Advanced Controllers with Multiple Setpoints ☑
Variable Air Volume (VAV) Configuration ☑
4 Load Sensors ☑
Variable Frequency Drives (VFDs) ☑
Demand-Controlled Ventilation (DCV) System ☑
Integrated Sensors for Temperature, Humidity, Air Quality ☑
5 AI and Machine Learning Algorithms ☑
Building Management System (BMS) Integration ☑
Advanced Sensors Network ☑
Edge and Cloud Computing Capabilities: ☑
Predictive Maintenance Tools ☑

Fig. 3. The checklist of smart components and services for HVAC system.



Please choose your desired sustainability certification: LEED- Neighborhood

Categories	Smart KPIs	Reference score	
SMART Building automation technologies - (optimization of energy consumption)	1.1. HVAC system	11	
	1.2. Water use in buildings	2	
	1.3. Lighting system	2	
	1.4. Buildings opening	2	
	1.5. Electricity management system	2	0.0
	1.6. Maintenance and commissioning	1	0.0
RES generation and supply	2.1. Renewable energy grid	22	4.4
Smart water	3.1. Water distribution network	8	0.0
	3.3. Irrigation Control system	6	1.1
	3.4. Grey water reclamation	7	0.0
Smart waste management	4.1. Waste collection systems	8	1.2
	4.2. Organic waste composter	2	2.0
Smart Social welfare	5.1. Community engagement and awareness	12	2.0
	5.2. Community equity	5	0.0
	5.3. Security, safety, and health provision	0	0.0
Smart management of outdoor environment	6.1. Smart nearby public station	0	0.0
	6.2. Outdoor light	7	0.0
	6.3. Parking areas	1	0.0
	6.4. Garden management work	2	0.0
	Total	100	14.7

Fig. 4. The last sheet of measurement tool (determining the sustainability or ESG protocols).

Table 2
List of possible certifications that can be achieved.

Engaged Level of smartness	Ranges of scores	Certifications
Level 1	26 to 37	Smart Basic
	38 to 50	Smart Basic+
Level 2	51 to 62	Smart Pro
	63 to 75	Smart Elite
Level 3	76 to 87	Smart Master
	88 to 100	Smart Supreme

5.2. *Strategy design and implementation*

In order to test the applicability of assessment framework of smartness, the selected case study is evaluated under various scenarios. As the usage of this case study is clearly residential, and the main purpose of smartening are to conserve resources and to enhance life quality, the scenarios are proposed based on needs of social housing through different points of view, including residents- centric and managers-centric scenarios. By grounding the investigation in the real needs and characteristics of residential living, this approach promises to yield insights that are both practically relevant and theoretically significant.

Fig. 5. An aerial perspective of the neighborhood.

5.2.1. Scenario zero: neighborhood auditing

In many studies, base-run phase is also considered as an opportunity to understand boundary conditions and the existing challenges which allows stakeholders to set a strategy design for the next phase. In this section, the checklist of smart KPIs, are filled based on the current state of the smart services in the neighborhood. Different procedures have been employed to collect data including in-field examination, technical map reading, and conducting an interview with cooperative's staff and commissioning engineers. Just to give an overview, in this neighborhood, heating is supplied by central condensing gas boilers, distributed, and emitted through radiators in dwellings rooms. All radiators are equipped with manual thermostatic valves to control the heat output, and there are no thermostats to regulate the overall temperature of the dwellings. Besides, fresh air and cooling needs can only be met by manual windows opening. All windows are also equipped with external solar shading. Besides, there are some digital screens in each building which announce the latest news and activities of society. In addition, an automatic irrigation system is already implemented for the green areas. The data collection on current status of neighborhood shows that the current score of smartness in this neighborhood is 14.1, 12.3, and 13.5 in average LEED, BREEAM, and DGNB, respectively. Results show that the most scores are adopted in building energy systems, particularly HVAC system and maintenance system planning.

5.2.2. Scenario one: residents-centric

The residents-centric scenario represents a pivotal approach within the broader context of smart city. Recognizing that the ultimate success of any housing regeneration strategy lies in its alignment with the needs, preferences, and expectations of residents, this scenario takes a bottom-up approach, focusing on the voices of the residents themselves. The foundation of this scenario is based on a questionnaire that was distributed among a few numbers of residents. Although all the questions were translated and designed in a simple way to be understood by all residents, this survey went beyond and necessitated individual accompaniment and presence to provide the necessary clarifications and explanations for the topic. Due to this necessity of respondents' accompaniment for face-to-face exploration, the survey focused on a few numbers of residents. The questions were meticulously designed to maintain neutrality and prevent any bias or provocation in shaping the residents' opinions on specific challenges. In this questionnaire, respondents were invited to assess the degree of difficulty and relevance of each problem in the neighborhood on a scale from 1 to 5. The content of the questionnaire is presented as supplementary material.

According to this questionnaire, the most important challenges of residents can be summarized into:

- Irregular pattern of waste generation, which despite waste collection creates a polluted smelling space in the corresponding room.
- Disorganized allocation of parking spaces.
- High electricity bills.
- The long waiting time for hot water supply.
- The darkness of the neighborhood and surrounding areas due to the high cost of energy.
- Difficulty in adjusting the temperature of the indoor environment (getting too warm or too cold).

In this regard, the potential smart solutions for fulfilling these challenges, can be the following smart solutions:

✓ Smart waste collection systems
✓ Smart parking system
✓ Smart renewable energy grid
✓ Smart domestic hot water system
✓ Smart outdoor light
✓ Smart HVAC system

Accordingly, taking into account the current status of the neighborhood (Scenario zero), the implementation of these smart solutions accounting the smart framework- average LEED as an example, can lead to relative increases of 23 %, 39 %, and 50 %, respectively, for levels 3 to 5. It's evident that upgrading various indicators at different levels of smartness may result in scores that range between these mentioned values, reflecting the nuanced impact of different enhancements.

5.2.3. Scenario two: managers-centric

In the context of urban regeneration, the policy makers' perspective and managers' priorities hold a significant value, as they often shape the direction and implementation of strategic interventions. Recognizing the essential role that managers play in the decision-making process, the manager-centric scenario was designed to integrate their insights, preferences, and practical considerations. To this end, a dedicated meeting was convened with the social housing's directors and engineers responsible for the neighborhood's development. In this meeting, various smart solutions, their potential requirements, and benefits have been showcased and discussed. The managers were not merely passive recipients of information but actively engaged participants, providing critical feedback on what they perceived to be priorities for their neighborhood. The objective of this meeting was to understand not only preferable smart solutions but also their actual applicability within the existing framework of the neighborhood, from managers' viewpoint. This approach ensured that the strategies derived were not only theoretically sound but also grounded in the real-world constraints and opportunities as seen by those who oversee the community's management. according to the meeting, managers' centric scenarios involve the implementation of the following smart solutions:

✓ Smart maintenance and commissioning
✓ Smart renewable energy grid
✓ Smart irrigation
✓ Smart water reclamation
✓ Smart engagement

Table 3 compares the interests and priorities of residents and managers at different depths of neighborhoods' smartification.

The initial examination of the results indicates that the majority of issues, motivated in the resident-centric scenario, are pertinent to KPIs capable of reducing energy costs and enhancing well-being within the neighborhood. Conversely, the manager-centric scenario draws attention to preserving the neighborhood's elements and utilizing available resources, which can be justified due to their expertise and knowledge of the available resources. Also, due to the high importance of energy issues in sustainability certifications and the significant advancement of ICT technologies within this domain, which has provided more intelligent solutions compared to other KPIs, it can be subsequently seen that focusing on these KPIs can bring significant smart readiness score in the overall level of smartness of the neighborhood. As can be observed having smart initiatives can result in various scores which highlight the significant contribution of this framework in clarifying not only the details of level of smartness that are supposed to be applied, but also the thematic areas that are considered under the conceptual projects of smartening neighborhoods among stakeholders.

6. Conclusion

Despite the large number of sustainability assessment protocol that have been established over last two decades, targeting scales from buildings to the neighborhoods there is still no assessment framework to measure the level of "smartness" within a specific area. Particularly, there are three main challenges that may justify this research gap. Hence, this framework presents a functional structure that underpins intricate urban planning and design strategies oriented around smart city concepts and fostered the continuity and effectiveness of urban

Table 3
List of scores under Average LEED certification within different scenarios and depth of smartness.

Smart KPIs	Scenario zero	Scenario one: Resident centric			Scenario two: Manager centric		
	Current status	*Smartness Level 1*	*Smartness Level 2*	*Smartness Level 3*	*Smartness Level 1*	*Smartness Level 2*	*Smartness Level 3*
1.1. HVAC system	4.5	9	13.5	18	6.8	6.8	6.8
1.2. Water use in buildings	0.5	1	1.5	2	0.5	0.5	0.5
1.3. Lighting system	1.5	1.5	1.5	1.5	1.3	1.3	1.3
1.4. Buildings opening	1	1	1	1	0.4	0.4	0.4
1.5. Electricity management system	0	1	1.5	2	0	0	0
1.6. Maintenance & commissioning	0	0	0	0	5.5	8.3	11
2.1. Renewable energy grid	2.9	7.3	10.9	14.5	3.5	4.9	7
3.1. Water distribution network	0	0	0	0	0	0	0
3.3. Irrigation Control system	0.9	0.9	0.9	0.9	1	1.5	2
3.4. Grey water reclamation	0	0	0	0	1	1.5	2
4.1. Waste collection systems	0.6	2	3	4	0.6	0.6	0.6
4.2. Organic waste composter	1	1	1	1	1	1	1
5.1. Community engagement and awareness	1.1	1.1	1.1	1.1	3	4.5	6
5.2. Community equity	0	0	0	0	0	0	0
5.3. Security, safety, and health provision	0.1	0.1	0.1	0.1	0.3	0.3	0.3
6.1. Smart nearby public station	0	0	0	0	0	0	0
6.2. Outdoor light	0	2.5	3.8	5	0	0	0
6.3. Parking areas	0	0.5	0.8	1	0	0	0
6.4. Garden management work	0	0	0	0	0	0	0
	14.1	28.9	40.5	52.1	24.7	31.4	38.7
	No certification	**S** Basic	**S** Basic+	**S** Pro	**S** Basic	**S** Basic	**S** Basic +

regeneration initiatives in a more efficient and smarter way. To this end, a mixed-method approach is used to support the framework's development through three steps, including: i) selecting categories and KPIs based on existing and verified smart solutions collected from the literature, ii) assigning weights to the criteria based on novel indexes that reflect the main goal of smartening, iii) introducing measurement methods.

To be aligned with sustainability protocols, this framework incorporates a broad range of thematic KPIs distributed across several categories including water distribution management, building energy efficiency, waste management, and so on. An additional level of sophistication is introduced through weighted indexes that allows the quantification of these KPIs, offering stakeholders a reliable, yet adaptable, tool for evaluation. Indeed, the framework not only introduces actionable smart solutions for the engineers, policymakers, and community leaders, but also brings a measurement tool to quantify the level of smartness that can be adopted. By doing so, it paves the way for more focused investment, improved resource allocations, and ultimately, the realization of smarter and more efficient neighborhoods. One of the distinct features of this framework is the capability to be customized based on sustainability protocols, made evident by one of the indexes used for weight assignment to the KPIs. This index gauges the affinity between smart KPIs and their corresponding sustainability goals, allowing users to align these smartening assessments with their desired specific sustainability certifications. This feature renders the framework not just an evaluative tool for smartness, but also a means to gauge how such smartness contributes to sustainable living.

The applicability and adaptability of the framework have been tested through a case study implementation. Multifarious scores of smartness, derived from different scenarios that considered the current state of the neighborhood as well as the needs of residents and priorities of managers, demonstrated that the term of smart neighborhood, can be largely varied among stakeholders and experts. Besides, reaching different final scores based on different levels of smartness, in a single KPI, clarifies the broadness of technologies and efforts that can be encompassed as a smart city approach. Consequently, this framework can be employed as a benchmark among stakeholders to make transparent decisions about the regeneration activities and level of smartness and technologies that are going to be implemented in a real-world case study. To conclude, the main achieved outcomes of this research projects are:

- ✓ Develop an assessment framework to evaluate the level of smartness of neighborhoods, its domains, components, functions, and underlying technologies.
- ✓ Developing the technical checklists of technologies required for each level of smartness within each single indicator.
- ✓ An example of using a mixed-method approach to develop a KPI-based assessment framework.
- ✓ Develop a novel weight assignment method for smart KPIs encompassing critical indexes that reflect the main goals of smart solutions.
- ✓ Further extension of the SRI report to the neighborhood elements including other thematic KPIs including water distribution systems, waste management, social well-being, and outdoor space elements.

Due to the unique characteristics of the neighborhood-scale units discussed in the Introduction, and based on the same scale considered in the recognized international sustainability assessment tools, the proposed framework is also devoted to the neighborhood scale communities at international level; while the methodology assumed for developing the framework can be used as a reference to customize similarly new tools for adjusting the scale to districts, cities, and regions. As further developments for the neighborhoods scale, testing the framework on other case studies could provide insightful information for integrating new features.

In conclusion, the assessment framework presented in this research project does more than simply measure the 'smartness' of neighborhoods; it connects smart initiatives with their ultimate purpose, sustainability. It is an adaptable, multi-dimensional tool that not only fills a notable gap in existing research but also provides an empirical basis for future initiatives. By bridging the gap between smart technologies and sustainable outcomes, this framework serves as a cornerstone for the development of future neighborhoods that are not just sustainable, but also smarter.

CRediT authorship contribution statement

Milad Zoghi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation,

Visualization, Writing – original draft, Writing – review & editing. **Simone Ferrari:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Giancarlo Paganin:** Conceptualization, Project administration. **Giuliano Dall'O':** Conceptualization, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data have been attached as two supplementary materials.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scs.2024.105206.

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