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Sustainable MED Cities

Integrated tools and methodologies for sustainable Mediterranean cities

D3.1.3 Indicators for smart cities

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1. Executive Summary

A large number of indicators are necessary in order to support cities for applying city management systems and to implement **smart city** policies, programmes and projects (ISO 37122). Among others, these efforts aim to:

- respond to challenges such as climate change, by fundamentally improving how they engage society;
- serve people and improve quality of life for residents, businesses, and visitors using data and new technologies;
- achieve sustainability goals;
- facilitate innovation and growth;
- build a dynamic and innovative economy.

An integral element of smart cities that has evolved and advanced to early implementation stages is the **smart readiness indicator** (SRI) **of buildings**. This is a common EU rating scheme that depends on a building's capacity to accommodate smart-ready services for creating healthy, energy-efficient and comfortable indoor environment.[1] The approach addresses all main building services, including air-conditioning, domestic hot water, lighting, electricity, electric vehicle charging, building envelope functions, monitoring and control. The impacts are accessed in terms of energy efficiency and flexibility, indoor comfort, convenience, health and well-being, among others.

This report outlines the characteristics of related methods in order to quantify the building smart readiness indicator and smart cities. The presentation does not provide detailed information but rather outlines the SRI method and provides the necessary links to the available tools for quantifying the smartness of buildings. For smart cities, several

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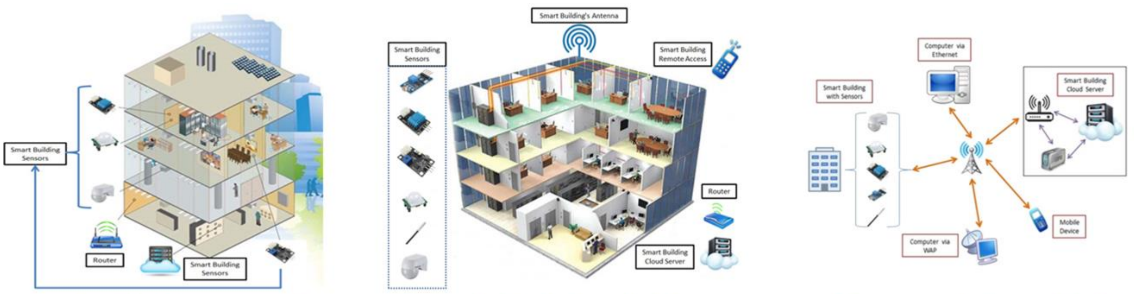
[1] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en

of the relevant indicators that are reviewed herein are already part of the CESBA MED sustainability assessment method (https://cesba-med.interregmed.eu). Relevant information that is suitable for integration in the overall concept are presented in this report. Considering that a smart city has several facets, the evaluation of a smart city is based on qualitative criteria using an expert's assessment based on the prescribed reference descriptions in order to assess and score the specific performance (Balaras et al. 2019).

2. Introduction

Technological advances can effectively support the evolution of buildings that are energy efficient, with functional, healthy, comfortable, safe, functional and productive environments. This concept is also reflected in the energy performance of buildings directive (EPBD 2018) that promotes the use of automation and controls and electronic monitoring in technical building systems. Furthermore, these processes are facilitated through the advances of internet of things (IoT) that greatly enhance the ability to handle big data by monitoring, processing, storing and analysing information from different building functions, equipment and operating conditions (Figure 1). As a result, it is possible to automatically and effectively control in real-time and optimize the operation of a building (Plageras et al. 2018).



Smart building components | Communication between building sensors and Cloud Server with users | Star communication architecture between sensors-user-building

Figure 1. Smart buildings and IoT; Adapted from Plageras et al. 2018.

There are various definitions for **smart buildings** that have been presented in the literature (Al Dakheel et al. 2020). The common features of smart buildings include:

- Automation in order to facilitate the automatic operation of equipment and appliances or perform automatic functions
- Multi-functionality in order to allow for multiple functions
- Adaptability in order to learn, predict and satisfy the needs of occupants and minimize the loads from the outdoor environment
- Interactivity in order to allow the interaction and data exchange among occupants and installations
- Efficiency in order to improve performance, reduce operating cost and save time.

The concept of the **smart city** has widely used during the past couple of decades, but there are various interpretations and focus of different features and attributes of its meaning (Lai et al. 2020; Hajek, Youssef and Hajkova 2022). For example, according to the European Commission (EC Smart Cities)

"*A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business*."

while the international standard on the indicators for smart cities (ISO 37122:2019) defines it as a

"city that increases the pace at which it provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life to those in the city (residents, businesses, visitors), now and for the foreseeable future, without unfair disadvantage of others or degradation of the natural environment"

The notion of a **smart city** is inclusive of numerous issues and features. It is greatly facilitated by the introduction and use of information and communication technologies (ICT) and the IoT methodologies for data exchange (Farzaneh et al. 2021). However, it is

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further inclusive of smarter features for all sectors and facilities, for example, urban transportation network, city water network, garbage and recycling networks, services, buildings. In addition, means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population (EC Smart Cities).

Accordingly, a **smart city** encompasses several issues and categories that involve several indicators (Figure 2). In practically all aspects the various applications involve data that will provide the necessary information for decision making and actions, from data collection, data transmission/reception, data storage and analysis (Syed et al. 2021). For this reason, they commonly include city-wide Wi-Fi networks that use 4G and 5G technologies, but this is only the first step to developing and facilitating data exchange. The main issues are briefly elaborated in the following paragraphs, placing an emphasis on smart buildings that exhibit a mature assessment method taking advantage of the emerging digital technologies.

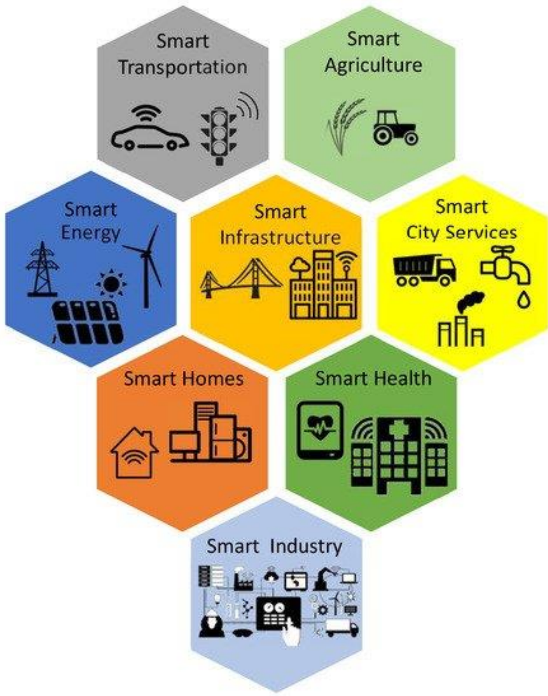

Figure 2. The main smart city issues (Syed et al. 2021).

Smart city services (Syed et al. 2021) encompass mobility, public services (e.g. water and waste management, environmental monitoring), and safety, among others. For example, track status of public transport and traffic to advise for alternative routes or guide drivers to available free parking spaces to save fuel cost, car emissions and time; monitor water quality and detect leaks; track content in waste bins to determine collection times and optimise disposal routes to reduce cost; track ambient environmental conditions to determine prevailing conditions or extreme events in order to advise citizens (e.g. pollution levels, heat waves).

Smart energy systems commonly refer to the main electricity grid or local (microgrids) or distributed energy conversion and distribution, especially for high developing urban areas. Moving into the future, the aim is to allow bi-directional flow of electricity and communication between electricity providers and consumers. Customer acceptance of new technologies and customer engagement is a key to the future EU power grid (EDSO). However, Distribution System Operators – DSOs, must carefully use and handle customer data in order to properly address and secure issues related to data privacy and security. Progressively, smarter grids will mandate a close cooperation between DSOs and transmission system operators - TSOs, at all levels for ensuring power stability, regulating demand etc, while providing real-time data for consumer use patterns, in order to better manage power generation from different energy sources in order to ensure an uninterrupted supply (Syed et al. 2021). In this evolving framework, local energy communities[2] and microgrids are growing following the introduction of the European directive for the internal electricity market (EU 2019) and national laws throughout Europe that enable prosumers, i.e. active consumer participation, individually or through citizen associations for generating, using, sharing or selling electricity, or providing flexibility services through demand-response and storage. In this direction there is a strong need for the development of development and implementation standards, engaging utilities in interacting with local microgrids.

Smart infrastructure is a key to a city's quality of living and involve the built environment in terms of construction and maintenance of roads, bridges in order to maintain proper city operation. **Smart transport** plays an important role and has multiple impacts on energy use and cost for public transport, environmental pollution and overall public

[2] https://energy.ec.europa.eu/topics/markets-and-consumers/energy-communities_en

services and accessibility of urban areas (Syed et al. 2021). The rapid ICT developments can significantly improve services for vehicle-infrastructure-pedestrian communication using real-time data for vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to pedestrian (V2P) or pedestrian to infrastructure (P2I) technologies. For example, use real-time GPS data to monitor traffic patterns and suggest alternate routes, monitor public transportation status and inform passengers, monitor available parking places and guide drivers.

Smart health refers to the use of ICT to improve health services (e.g. telemedicine services, the use of artificial intelligence for medical diagnosis, health trackers). **Smart agriculture** in the urban context involves the use of various sensors that are embedded into plants and soil to monitor various parameters in order to optimize growth, minimize water use, prevent diseases etc. Finally, **smart industry** is an economy sector that is experiencing major transformations towards higher efficiency and productivity at a lower cost, exploiting technological and ICT advances.

2.1. Smart Buildings

Smart buildings constitute an integral element of a smart city (Li et al. 2022). Typically, they exploit ICT, utilize various sensors along with equipment and appliances that are all interconnected to provide relevant information about the buildings prevailing conditions, operating status of the equipment and the occupants. Monitoring may include indoor ambient conditions, energy use, power demand, motion trackers, equipment actuators, etc. The information flows are by-directional, e.g. to inform the occupants about the prevailing conditions or energy use and allow them to control equipment operation from a distance, and even allow third parties to receive data about different operations and authorize load management, if agreed between the parties, to gain better energy prices.

The concept of a **smart readiness indicator** (**SRI**) was adopted by the energy performance of buildings directive (EPBD 2018) and further strengthened by the subsequent delegated regulation (EU 2020a) that outlines the calculation method and the implementing regulation (EU 2020b). Over the years, SRI has evolved and matured to a common EU rating scheme for evaluating the smartness of buildings. For the time being, it remains an optional scheme that undergoes a voluntary test and/or implementation phase in various EU Member States.

Smart technologies will be essential in the efforts to decarbonise the building sector and reach more energy efficient, environmentally friendly, healthy and comfortable indoor environments. The SRI method addresses **nine (9) major building services** (Figure 3):

- heating
- cooling
- ventilation
- domestic hot water
- lighting
- dynamic building envelope
- electricity
- electric vehicle charging
- monitoring and control.

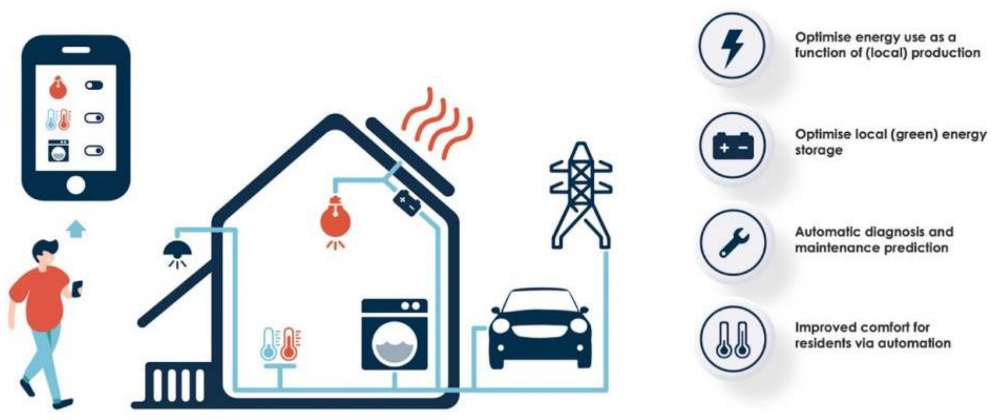

Figure 3. Illustration of representative smart building features (SRI 2022).

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Various smart-ready technologies are used to enable these services. However, they are defined in a technology-neutral way, for example, “provision of temperature control in a room”. For a given building, the assessment is performed for **seven (7) impacts**: 1) energy efficiency, 2) maintenance and fault prediction, 3) comfort, 4) convenience, 5) health, well-being and accessibility, 6) information to occupants, and 7) energy flexibility and storage. The outcome of the assessment is aggregated in an SRI score (see section 3.1) that quantifies the various building characteristics and functions in relation to a maximum smart readiness. Specific scores are also provided for **three (3) major building functionalities** in order to:

- Optimise energy performance
- Adapt operation to occupant needs
- Adapt operation to grid signals.

At building scale, final energy savings can average about 30% by exploiting advanced smart building technologies while improving the indoor environmental quality. Most of the measures are easy to implement resulting to significant energy savings, lower operational costs, and a short payback period. Some practical examples of smart technologies in buildings include:

- Digital technologies like smart thermostats that regulate and control indoor temperature (e.g. night setback) and adjust the operation of the heating or cooling systems (e.g. boiler or heat pump), and controls for artificial lighting (e.g. timers, occupancy sensors).
- Smart technologies like automated controls for operating shading devices, and controls to operate ventilation systems based on air-quality measurements, which improve indoor air quality and health, indoor comfort conditions and overall well-being.
- Intelligent programming and demand control of energy use equipment (e.g. white appliances, electric vehicles) to achieve significant energy cost savings and

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contribute to the balance of the electric grid that is progressively becoming more dependable to power generation from variable renewables.

Various information and other resources are available online for supporting stakeholders to implement the SRI scheme (SRI 2022). The SRI assessment package that includes the calculation sheet, a practical guide and training material, is readily available on request.[3]

2.2. Smart Cities

Numerous indicators affect the smart city transformation readiness that have been specified by various organizations (Yigitcanlar et al. 2022), including European (e.g. the Committee for Standardization - CEN, Committee for Electrotechnical Standardization - CENELEC, Telecommunications Standards Institute – ETSI) and international (e.g. the Standardization Organization - ISO, Telecommunication Union – ITU) and the United Nation's (UN) Sustainable Development Goals (SDG). A review of various Australian smart cities has revealed the common use of 16 indicators (Yigitcanlar et al. 2022), including:

- **Environment** - Sustainability & Accessibility: Sustainable Commuting (percentage of public transport commuters); Sustainable Vehicles (percentage of electric or hybrid electric private vehicles); Sustainable Energy (number of households with PV and solar thermal collectors installed per 100,000 people); Sustainable Buildings (number of buildings with a 4+ score under the Australian Built Environment Rating System per 100,000 people)
- **Economy** - Productivity & Innovation: Economic Productivity (median income); Labour Force Participation (percentage of employment); Innovation Industries (percentage of knowledge intensive industries); Talent Pool (percentage of knowledge workers in population)

[3] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-implementation_en

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- **Society** - Liveability & Wellbeing: Health Status (percentage of population with private health insurance); Safety and Security (number of annual offences per 100,000 people); Housing Affordability (percentage of rented households at a cost of less than 30% of total household income); Socioeconomic Progress (percentage of low-income individuals)
- **Governance** - Governance & Planning: Local Government Dispersion (urban landscape); Public Wi-Fi (number of free Wi-Fi locations per 100,000 people); Broadband Internet (percentage of total areas covered by the national broadband network); Smart City Policy (Yes in place = 2, In discussion = 1, None = 0).

Another literature review (Ependi et al. 2022) identified 19 indicators for smart governance that originate from different categories including among others: public services, infrastructures and buildings, open and transparent government data, real-time data monitoring, internet and Wi-Fi coverage, disaster and emergency preparedness, public transport, multi-level electronic governance, health care, organization, innovative involvement in decision making, citizen participation, smart city policies.

The main characteristics of a smart city consist of four major attributes (Khan et al. 2022) that are illustrated in Figure 4 including several categories (but not limited to):

- Sustainability that includes urban infrastructure, energy, climate change, pollution, waste, social, economic and health;
- Smartness that includes smart environments, living, mobility, governance, people and economy.
- Urbanization that includes technology, infrastructure, governance and employment;
- Quality of life that includes emotional and financial wellbeing of the community.

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Figure 4. Smart city characteristics. Adapted from Khan et al. 2022.

Accordingly, a smart city encompasses several issues and categories that involve several indicators (Figure 2). In practically all aspects the various applications involve data that will provide the necessary information for decision making and actions, from data collection, data transmission/reception, data storage and analysis (Syed et al. 2021). For this reason, they commonly include city-wide Wi-Fi networks that use 4G and 5G technologies, but this is only the first step to developing and facilitating data exchange. The main issues are briefly elaborated in the following paragraphs, placing an emphasis on smart buildings that exhibit a mature assessment method taking advantage of the emerging digital technologies.

The internet of things (IoT) with a network of sensors, software and various other embedded technologies have unleashed a multitude of different services and various features that advance the smart city concept (Syed et al. 2021). By 2025 it is estimated that over 75 billion devices will be connected to the internet allowing real-time data exchange and analysis to control and optimize operation of devices, appliances and various equipment. In this direction, emerging issues involve security and privacy schemes, data transfer standards, storage techniques and low power hardware, among others.

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The United for Smart Sustainable Cities - U4SSC initiative has presented a methodology for data collection and key performance indicators to evaluate ICT´s contributions for smart sustainable cities in three dimensions, i.e. economy, environment, society & culture (U4SSC 2017). The indicators are used to collect relevant data for measuring performance and progress of cities towards becoming smarter and more sustainable and for achieving the Sustainable Development Goals (SDGs).

To further support the development of **smart cities** the relevant **international standard 37122** specifies **20 sectors** and a total of **81 indicators** (ISO 37122:2019). The standard can be used to assess the maturity and performance of a smart city, placing an emphasis on transportation and energy sectors that are allocated the highest number of indicators (Kristiningrum and Kusumo 2021).

The various sectors and the corresponding indicators are summarized in Table 1 (ISO 37122:2019). The total number of indicators under each sector are shown in the parenthesis.

Table 1. Indicators for smart cities (ISO 37122:2019).

Energy (10)	1-Electrical & thermal energy from wastewater (% of total), 2-Electrical & thermal energy from wastewater (GJ per capita), 3-Electrical & thermal energy from solid waste or other liquid waste treatment (GJ per capita), 4-Electricity from decentralised production systems (% of total), 5-Storage capacity of energy networks (% of total energy consumption), 6-Street Lighting managed by a management system (% of total), 7-Street lighting refurbished & newly installed (% of total), 8-Public buildings requiring renovation/refurbishment (% of total), 9-Buildings with smart energy meters (% of total), 10-Electric vehicle charging stations per registered electric vehicle (number)
Environment and climate change (3)	1-Buildings constructed or refurbished in the last 5 years in compliance with green building principles (% of total constructed or refurbished), 2-Real-time air quality monitoring stations (Number per km^2), 3-Public buildings with monitoring indoor air quality (% of total)
Finance (2)	1-Revenues collected from the sharing economy (% of own-source revenue), 2-Payments to the city paid electronically based on electronic invoices (% of total)
Governance (4)	1-Online visits to the municipal open data portal (Annual number per 100 000 population), 2-Percentage of City services accessible and requested online (%), 3-Response time to inquiries (Average days), 4-Downtime of city’s IT infrastructure (Average hours)
Health (3)	1-Population with an online unified health file accessible to health care providers (%), 2-Medical appointments conducted remotely (Annual number per 100,000 population), 3-Population with access to real-time public alert systems for air and water quality advisories (%)
Housing (2)	1-Households with smart energy meters (%), 2-Households with smart water meters (%),
Population and social conditions (4)	1-Public buildings accessible by persons with special needs (%), 2-Municipal budget allocated for mobility aids, devices and assistive technologies to citizens with special

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	needs (%), 2-Marked pedestrian crossings equipped with accessible pedestrian signals (%), 4-Municipal budget for programmes on bridging the digital divide (%)
Recreation (1)	1-Public recreation services that can be booked online (%)
Safety (1)	1-City area covered by digital surveillance cameras (%)
Solid Waste (6)	1-Waste drop-off centres (containers) equipped with telemetering (%), 2-Population with door-to-door garbage collection with an individual monitoring of household waste quantities (%), 3-Waste used to generate energy (%), 4-Plastic waste recycled (%), 5-Garbage bins that are sensor-enabled (%), 6-Electrical and electronic waste that is recycled (%)
Sport and culture (4)	1-Online bookings for cultural facilities (Annual number per 100,000 population), 2-City's cultural records that have been digitised (%), Public library book and e-book titles (Annual number per 100,000 population), City population that are active public library users (%)
Telecommunication (3)	1-City population with access to sufficiently fast broadband (%), 2-City area under a white zone/dead spot/not covered by telecommunication connectivity (%), 3-City area covered by municipally provided Internet connectivity (%)
Transportation (14)	1-City streets and thoroughfares covered by real-time online traffic alerts and information (%), 2-Users of sharing economy transportation (Annual number per 100,000 population), 3-Vehicles registered in the city that are low-emission vehicles (%), 4-Bicycles available through municipally provided bicycle-sharing services (Annual number per 100,000 population), 5-Public transport lines equipped with a publicly accessible real-time system (%), 6-City's public transport services covered by a unified payment system (%), 7-Public parking spaces equipped with e-payment systems (%), 8-Public parking spaces equipped with real-time availability systems (%), 9-Traffic lights that are intelligent/smart (%), 10-City area mapped by real-time interactive street maps (% of the city's total land area), 11-Vehicles registered in the city that are autonomous vehicles (%), 12-Public transport routes with municipally provided and/or managed Internet connectivity for commuters (%), 13-Roads conforming with autonomous driving systems (%), 14-City's bus fleet that is motor-driven (%)
Wastewater (5)	1-Treated wastewater being reused (%), 2-Biosolids that are reused (% on dry matter mass basis), 3-Energy derived from wastewater (% of total energy consumption of the city), 4-Total amount of wastewater in the city that is used to generate energy (%), 5-Wastewater pipeline network monitored by a real-time data-tracking sensor system (%)
Water (4)	1-Drinking water tracked by real-time, water quality monitoring station, 2-Real-time environmental water quality monitoring stations (Annual number per 100 000 population), 3-City's water distribution network monitored by a smart water system (%), 4-Buildings in the city with smart water meters (%)
Urban/local agriculture and food security (3)	1-Annual municipal budget spent on urban agriculture initiatives (%), 2-Total collected municipal food waste sent to a processing facility for composting (Annual tonnes per capita), 3-City's land area covered by an online food-supplier mapping system (%)
Urban planning (4)	1-Citizens engaged in the planning process (Annual number per 100 000 population), 2-Building permits submitted through an electronic submission system (%), 3-Average time for building permit approval (days), 4-City population living in medium-to-high population densities (%)

Creating a vision for smart cities and communities (ISO 37106:2021) is an important first step and various resources are available to advance towards an action plan (SmartCitiesCouncil, EU Smart Cities). Apparently, there is no one-size-fits-all model but common characteristics include the innovative use of data resources and technological advances that need to be combined with organizational change, in order to develop a city's own vision.

3. Evaluation and Normalized Scores

The quantification of the relative performance for smart buildings and smart cities as an aggregated score is elaborated in the following sections. For buildings, the score is defined using the smart readiness indicator following qualitative approaches of various building services based on an expert assessment. For cities, the score is based on qualitative criteria for the expert opinion and assessment of qualitative criteria that reflect the different stages of smart cities. The normalization and scoring process for converting the indicator values into a common basis (scale) follows the approach used in the CESBA MED process (Moro 2017) that is common with other sustainability assessment and rating systems (Balaras et al. 2019).

In each case, the value of an indicator is dimensionalized and rescaled in an interval that corresponds to a performance below a standard level, which takes a value of "-1", up to an advanced performance, which takes a value of "+5". A score of "0" corresponds to the indicator's minimum acceptable performance according to the minimum requirement of a standard or other relevant regulation that is mandated by law, or the value that corresponds to common practice. Figure 5 illustrates the normalization process for deriving the common scores of indicators for which "higher is better" as a linear correlation between the two benchmarks at zero and five.

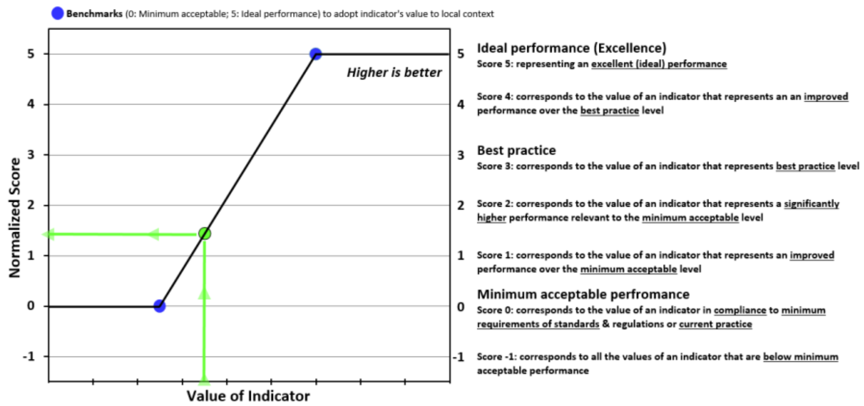

Figure 5. Common normalized scores for different indictor values.

Although currently there are no minimum mandates for smart buildings or smart cities, there are some common features that can be used and allocated for defining the corresponding benchmarks in the common scale. For example, a score of "-1" corresponds to a building that has no smartness with an SRI of 0%. On the other end, a building with an SRI of 100% corresponds to the highest level of building smartness that is assigned to a score of "+5". The minimum standard that corresponds to current building practices with some basic features of smart controls (e.g. indoor thermostats) are assigned to a score of "−1".

3.1. SRI for Smart Buildings

For a building, the smart readiness indicator (SRI) is assessed against the **seven** desired **impact criteria** (Figure 6), for example, energy efficiency, comfort, convenience. The impact scores per impact criterion are summed for those assessed for each of the **nine** major **building services** (domains), see section 2.1. Specific scores are then accumulated for three (3) major building functionalities of building smartness (Figure 6) in order to:

1. Optimise energy performance (includes 2 impact criteria)
2. Adapt operation to occupant needs (includes 4 impact criteria)
3. Adapt operation to grid signals (includes 1 impact criterion)

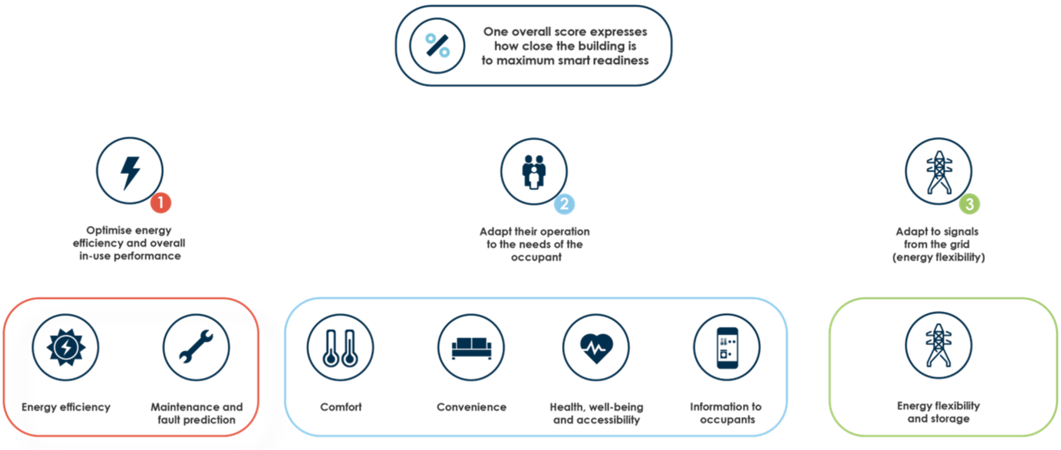

Figure 6. Illustration of the three major building functionalities and seven impact criteria (SRI 2022).

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Finally, the outcome of the assessment is aggregated into an **overall SRI score** (Figure 7) that quantifies how close the building is to the maximum smart readiness. The SRI score is the ratio of the impact scores from the assessed smart ready services to the maximum obtainable score, i.e. the sum of all impacts in case all smart services are implemented at the highest functionality level. Reaching an overall score of 100% indicates that a building has the highest currently possible level of smartness. On the lower end, a score of 0% refers to a building that has no smartness.

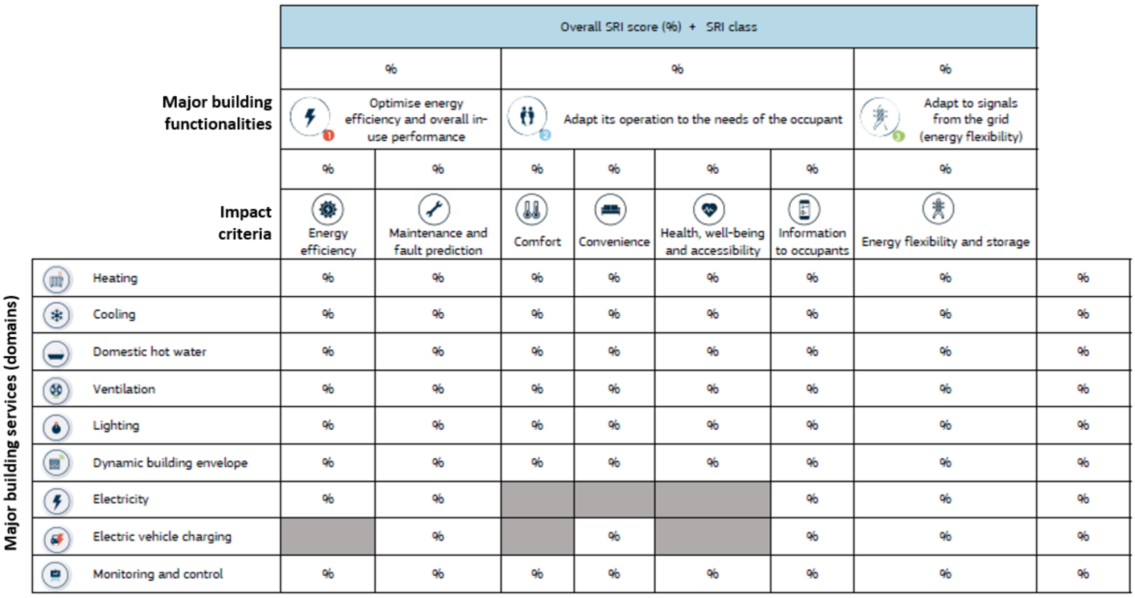

Figure 7. Calculation of scores at different levels of detail (SRI 2022).

To facilitate the calculation process, default weighting factors are all equally allocated for the calculation of the final score. In other words, the default assumption is to assign equal weights for the aggregation of the nine major building services (domains) to the seven impact criteria and finally to the three major building functionalities. This means that they are all equally important.

Accordingly, each functionality is equally weighted by one third in the calculation of the SRI score (Figure 8). The impact criteria are also equally weighted for the calculation of the score for each functionality. For example, the optimized energy functionality contributes by 33.3% to the overall SRI score, while each one of the two impact criteria (energy efficiency and maintenance/fault) will contribute by 16.7% each for the calculation of the SRI score.

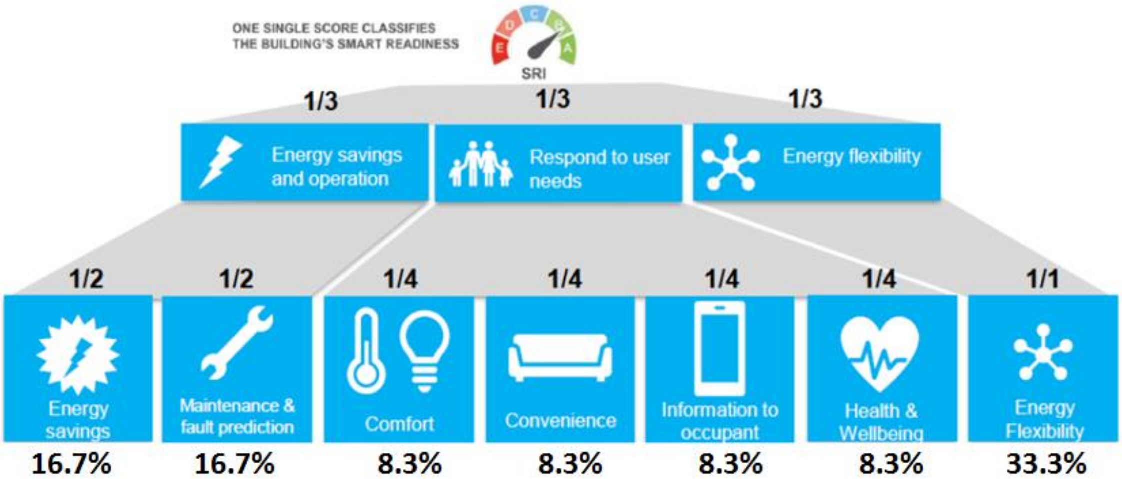

Figure 8. Breakdown of the weighting factors in the calculation of the SRI score for the three major building functionalities and the seven impact criteria (SRI 2022).

The default weights are set according to the relative importance of each domain in the energy balance of the building, wherever deemed relevant (and equal or fixed weighting factors elsewhere). Default weighting factors are available for residential and non-residential buildings. These differentiations are due to the differences in the relative importance of some of the domains; for example, the use of domestic hot water is significant in residential buildings but may be insignificant in some other non-residential buildings. The default weighting factors are also different for the five EU climate zones that have been defined due to differences in relative importance of heating (northern Europe) or cooling (southern Europe). If available, the expert may estimate different weighting factors by performing an energy balance of the building or using data for the different end uses from an energy performance certificate. During future implementation of the SRI method, national weighting factors will be defined by the EU Member States.

3.1.1. Assessment Methods

There are two assessment methods that focus on qualitative approaches of various building services based on an expert assessment. A **simplified method** can be used with a simplified service catalogue (Verbeke et al. 2020) that includes only 27 pre-defined services (Figure 9). The method can be used with existing residential buildings or small non-residential buildings that have low complexity. The approach utilizes a check-list and the overall assessment is typically completed in less than an hour. This method is suitable for a self-assessment of a building.

From non-smart ... to maximum smartness

Domain	Code	Service group	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Heating	H-1a	Heat control - demand side	Heat emission control	No automatic control	Central automatic control (e.g. central thermostat)	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection
Heating	H-1b	Heat control - demand side	Emission control for TABS (heating mode)	No automatic control	Central automatic control	Advanced central automatic control	Advanced central automatic control with intermittent operation and/or room temperature feedback control	
Heating	H-1c	Control heat production facilities	Storage and shifting of thermal energy	None	HW storage vessels available	HW storage vessels controlled based on external signals (from BACS or grid)		
Heating	H-1d	Heat control - demand side	Control of distribution pumps in networks	No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal) estimations)	Variable speed pump control (external demand signal)
Heating	H-1f	Heat control - demand side	Thermal Energy Storage (TES) for building heating (excluding TABS)	Continuous storage operation	Time-scheduled storage operation	Load prediction based storage operation	Heat storage capable of flexible control through grid signals (e.g. DSM)	
Heating	H-2a	Control heat production facilities	Heat generator control (all except heat pumps)	Constant temperature control	Variable temperature control depending on outdoor temperature	Variable temperature control depending on the load (e.g. depending on supply water temperature set point)		
Heating	H-2b	Control heat production facilities	Heat generator control (for heat pumps)	On/Off-control of heat generator	Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)	Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	Variable control of heat generator capacity depending on the load AND external signals from grid	
Domestic hot water	DHW-1a	Control DHW production facilities	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	Automatic control on / off	Automatic control on / off and scheduled charging enable	Automatic control on / off and scheduled charging enable and multi-sensor storage management		
Domestic hot water	DHW-1b	Flexibility DHW production facilities	Control of DHW storage charging	None	HW storage vessels available	Automatic charging control based on local availability of renewables or information from electricity grid (DR, DSM)		
Domestic hot water	DHW-1d	Control DHW production facilities	Control of DHW storage charging (with solar collector and supplymentary heat generation)	Manual selected control of solar energy or heat generation	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge and demand-oriented supply or multi-sensor storage management	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge, demand-oriented supply and return temperature control and multi-sensor storage management	
Domestic hot water	DHW-2b	Control DHW production facilities	Sequencing in case of different DHW generators	Priorities only based on running time	Control according to fixed priority list: e.g. based on rated energy efficiency	Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)
[illegible]	[illegible]	Information to occupants and facility	Report information regarding domestic hot water	[illegible]	Indication of actual values	Actual values and historical	Performance evaluation	Performance evaluation including forecasting and/or benchmarking; also

Figure 9. Examples of functionality levels for heating and domestic hot water (SRI calculation sheet).

A **detailed method** is also available that utilizes a detailed service catalogue (Verbeke et al. 2020) that includes 54 pre-defined services (Figure 9). The method is typically used

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with new buildings and non-residential buildings that have a higher complexity. The approach requires an on-site inspection and walk-through audit that is typically completed in about a day. This method mandates the involvement of an expert and engagement of the building's facility manager.

The relevant services for a specific building are first identified following the so-called **triage process** that depends on the presence of the specific technical domains in the building. Currently the experts, and the authority having jurisdiction in the future implementation, determine for each of the technical building systems if they are available in the building or not, or whether they should be in accordance to minimum code requirements. Accordingly, a specific smart service is considered and potentially used on the basis of whether it is:

- Not relevant for the specific building. For example, services to control a heat pump in the event that the building is not equipped with such equipment; services for electrical vehicle (EV) chargers in the event that there are no parking spaces available; services to control domestic hot water storage in the event that there is no such equipment installed. These services are then not taken into account in the calculation.
- Relevant because they are present in the particular building. The actual impacts of each service are compared against the maximum impacts by calculating the SRI score ratio.
- Relevant because they should be present according to ongoing regulations and relevant policies. For example, although there is no battery storage present in the building, the potential impacts can be taken into account for defining the maximum impacts that is used as a denominator in the calculation of the SRI score ratio.

Accordingly, the SRI score is calculated as the ratio of the impact score (score a) that is determined from an assessment of the smart ready services for a specific building to the maximum obtainable score for the same building (score b) when all smart services are implemented at the highest functionality level (Figure 10). Following the triage process, some services may not be relevant for a specific building and as a result it will not be considered nor influence the maximum obtainable score. Accordingly, this normalization process adapts the maximum score for a specific building to a lower value than the theoretical maximum that accounts for all possible services. For example, a residential building may have negligible cooling loads and thus no need for cooling in northern Europe and as a result the building will not have smart cooling controls. As a result, the maximum score for the specific building (score b) will not account the potential impacts of smart cooling controls.

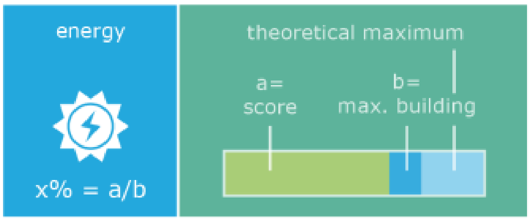

Figure 10. Calculation of SRI score Illustrated SRI certificates (SRI 2022).

The calculated scores can be presented in a **SRI certificate** like the ones illustrated in Figure 11 and potentially may be integrated in the energy performance certificate. The backside of the certificates will include additional information about the building's functionalities and technologies. Progressively a number of relevant publications and case studies that utilize SRI are becoming available and may be used for reference (Apostolopoulos et al. 2022, Athanasaki and Tsikaloudaki 2022, Canale et al. 2021, Fokaides et al. 2020, Vigna et al. 2020). Efforts are also made to expand the SRI for buildings to larger context of districts based on the load shifting potential, energy storage capacity and active interaction with the energy grids (Salom et al. 2021, Marzinger and Osterreicher 2020).

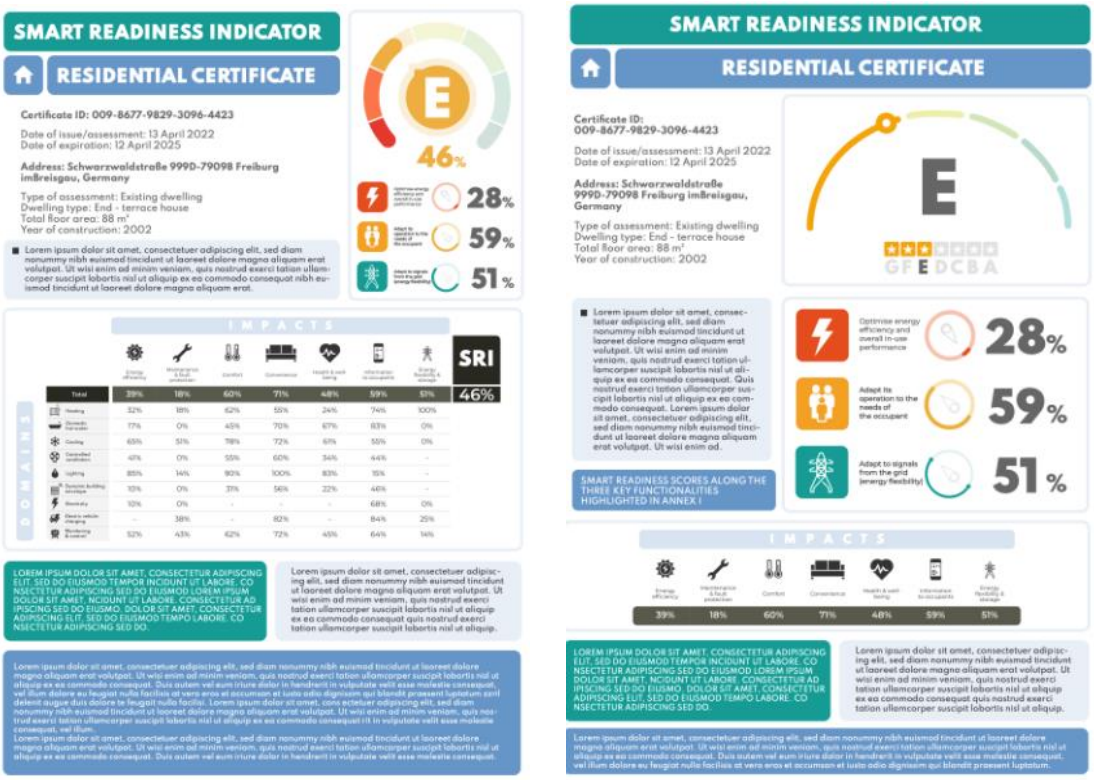

Figure 11. Illustrated SRI certificates (SRI 2022).

During the testing period of the SRI development, the methodological framework was used in a number of case studies throughout Europe, using both the simplified and detailed methods for some of them (Verbeke et al. 2020). At the end, stakeholders from a total of 21 member states participated in this exercise, completing 112 calculation sheets (43 from southern, 38 from western, 14 from northern, 7 from north-eastern and 10 from south-eastern Europe) corresponding to 81 buildings, of which both calculation methods were used for 31 buildings. The dataset included 47 residential buildings and 65 non-residential buildings (including 36 offices, 14 schools, 5 healthcare and 13 other buildings) from various age bands.

The results of the SRI scores are illustrated in Figure 12. Both calculation methods (simplified and detailed) did not have statistically significant differences. Accordingly, the simplified method manages to sufficiently estimate the building's smart readiness although it utilizes a part of the possible service-catalogue (Verbeke et al. 2020).

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However, there are significant differences between residential and non-residential buildings. The results indicate relatively lower scores for residential buildings (median of 25.6% using method A and 28.7% using method B), which was anticipated since smart ready services are usually encountered in more advanced technical building systems of non-residential buildings (median of 52.4% using method A and 49.7% using method B).

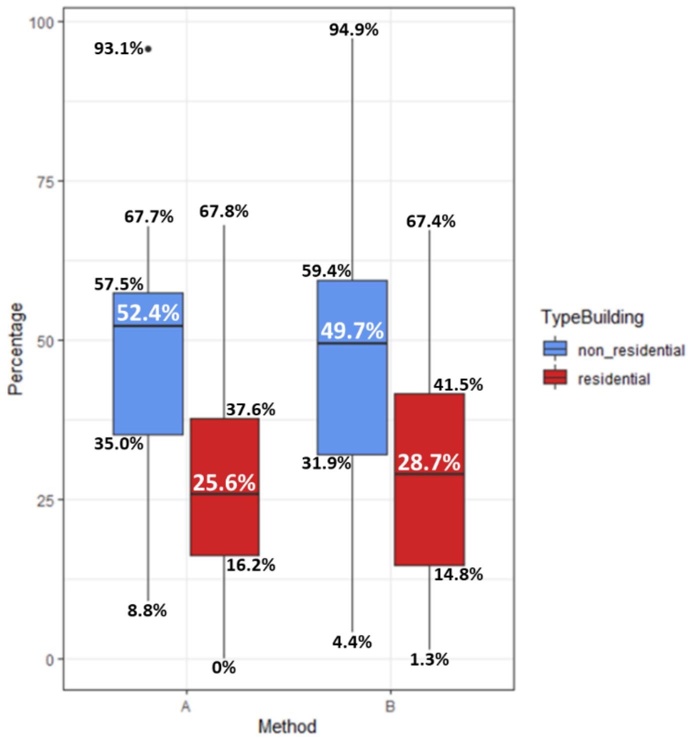

Figure 12. Box plots with average SRI scores for residential and non-residential buildings using both calculation methods certificates (SRI 2022).

In the absence of more detailed national data, these indicative results (Figure 12) can be used for benchmarking and normalizing the SRI scores. Using the results from the simplified method A,

for **non-residential buildings**,

- The minimum acceptable performance as current practice (score 0 in Figure 5) is assigned to a numerical value of the SRI indicator at the 25th percentile or 35%

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- The excellent performance (score 5) is assigned at 100% that corresponds to the ideal (theoretical maximum) value.

for **residential buildings**,

- The minimum acceptable performance (score 0) is assigned to a numerical value of the SRI indicator at the 25^{th} percentile or 16% and
- The excellent performance (score 5) at about 100% that corresponds to the ideal (theoretical maximum) value.

3.2. Stages of Smart Cities

Smart cities are characterized by several elements (Figure 13) that exploit networks and services, which are made more efficient using digital solutions, to better serve citizens and businesses, including among others:

- Smart and efficient buildings,
- Lower use of resources,
- Lower emissions,
- Smarter urban transport networks,
- Upgraded water supply and waste disposal,
- More interactive and responsive city administration,
- Safer public spaces.

Figure 13. Illustration of the main clusters for a smart city (Source: NIST https://www.nist.gov/el/cyber-physical-systems/smart-americaglobal-cities/global-city-teams-challenge).

As illustrated, a smart city involves the use of digital technologies along with several other clusters. It is important to underline that a single element does not make a smart city but rather need a good balance and interactive approach. Furthermore, studies have revealed that there is no linear correlation between city smartness and emissions, and there are no notable changes with time (Yigitcanlar and Kamruzzaman 2018). Accordingly, there is a need to properly align smart city strategies that will strengthen and support sustainability.

The digitalization of the energy market has attracted a lot of attention that involve smart meters and smart grids in the framework of the EU electricity directive (EU 2019). The evolving energy networks can automatically monitor energy flows, i.e. electricity fed into the grid or electricity used from the grid. In addition, they can adjust to changes in the energy supply and demand, i.e. transmitting and receiving real time data for information, monitoring and controlling loads. For example, enable buildings to adapt energy use to different energy prices or grid loads). Smart energy networks can support bidirectional flow of energy and communication from generation, to transmission, to distribution, to consumption. Collected data can be used to automatically monitor

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energy flows and adjust energy supply and demand. The challenges ahead mainly need to facilitate the integration of variable power generation from renewables, the integration of new loads (e.g. energy storage, charging EVs) and the need to maintain stability and efficiency of the system (Figure 14).

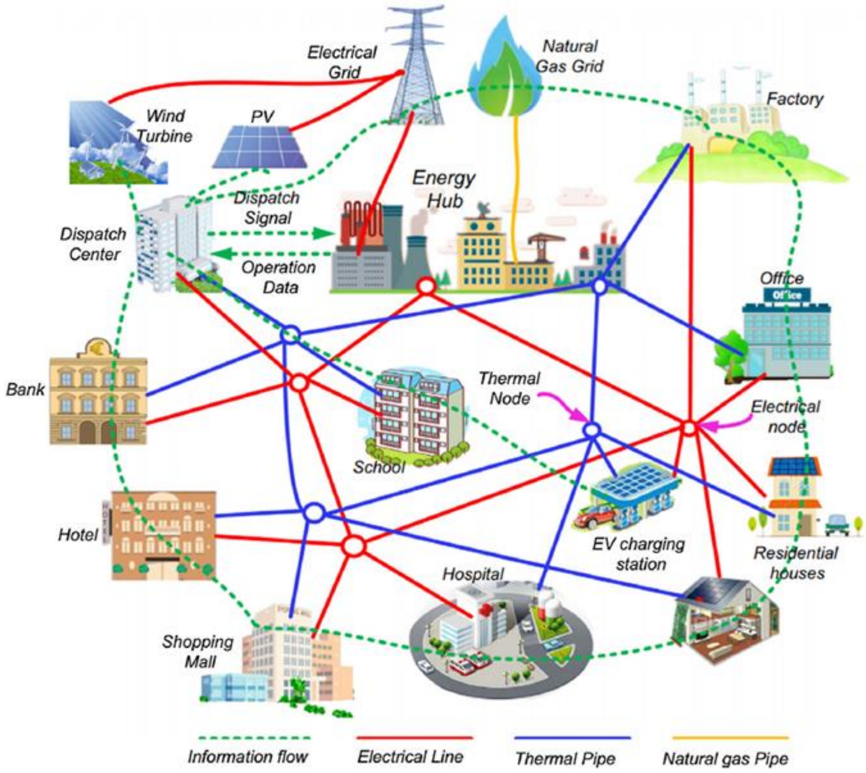

Figure 14. Future energy hubs (Zhang et al. 2018).

In the urban context, buildings are transformed from relatively passive loads on the grid to dynamic partners in the electricity sector, providing (potentially selling) electricity & exchanging information that allows for load balancing to support a stable-reliable grid.[4] However, usually the inherent complexities as a result of all the integral elements, city governments and local authorities may be overwhelmed missing the required expertise and capabilities, may fail to gain the anticipated benefits (Ruhlandt 2018).

The assessment of smart cities has been attempted by various methods that exploit different indicators to derive a smart city index (Akande et al. 2019). For example, the cities in motion index – CIMI (Berrone and Ricart 2016) was used to evaluate 181 cities

[4] https://www.ashrae.org/File%20Library/About/Leadership/new_energy_future_web_061518.pdf

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around the world to reveal the top-ten list of the smartest cities (Silva et al. 2018): City of New York (USA), London (UK), Paris (France), San Francisco (USA), Boston (USA), Amsterdam (Netherland), Chicago (USA), Seoul (South Korea), Geneva (Switzerland), and Sydney (Australia). In another effort, European capital cities were evaluated using 32 indicators to assess smartness and sustainability using the UNECE-ITU framework with publically available Eurostat data (Akande et al. 2019). The results indicate a small correlation with the city size and its population, but a positive correlation with wealth expressed by the city's gross domestic product per citizen. The top-five European capitals include Berlin, Stockholm, Helsinki, London, Copenhagen, Paris, Amsterdam, Prague, Vienna and Dublin. The European Commission has also developed a dedicated website for cities and urban development to facilitate cities to use technical solutions in order to enhance the performance and management of the urban environment (EU Smart Cities) and a smart cities marketplace website.[5]

The review of 16 different assessment frameworks, including 8 smart city and 8 urban sustainability that utilize a total of 958 indicators has revealed different emphasis on smart technologies, energy and environmental indicators along with social and economic aspects (Ahvenniemi et al. 2017). Progressively the city smartness assessment expands the boundaries beyond smart solutions to include sustainability indicators related to energy, environmental, economic or social issues. As a result, instead of smart cities, an emerging term to use is "smart sustainable cities" in order to keep the sustainability priorities along the efforts to enhance the city smartness.

The variability of relevant definitions results to different hurdles for analysing and planning the various facets of smart cities (Ahvenniemi et al. 2017). Popular assessment frameworks include various tools (Hajek, Youssef and Hajkova 2022), for example, a research project on ranking European medium-sized smart cities (Giffinger et al. 2007), Assessing Smart City Initiatives for the Mediterranean Region – ASCIMER (Monzon 2015), SmartEnCity (Quijano et al. 2016), CITYkeys (Bosch et al. 2017), China smart city performance (Shen et al. 2018), the Lisbon ranking for smart sustainable cities in Europe

[5] https://smart-cities-marketplace.ec.europa.eu/

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(Akande et al. 2019), and POCITYF (Angelakoglou et al. 2020). However, the challenge remains that the aggregate ranking scores do not solely address the smart city features, but they include numerous other sustainability indicators. In the concept of the CESBA method the approach is to include in the sustainability assessment framework an indicator that addresses the smartness aspects of a city, like the SRI for buildings that was previously presented.

3.2.1. Assessment Method

A smart city involves several issues and numerous indicators, some of which are interweaved with more than one categories (Khan et al. 2022), for example, transportation infrastructure under the sustainability issue of urban systems with smart transportation; non-renewable and renewable and clean energy under the sustainability issue of energy with smart energy; atmospheric pollution under the emissions issue with smart environment.

A smart city can evolve through different stages (Figure 15) that can be interpreted as different smart city generations (Khan et al. 2022). The baseline can be characterized by the efforts of a city to adapt different technologies and progressively grow from the first level (SC-1) that is mainly technology-driven, to the citizen- and government-driven and industry 4.0 (e.g. 4G, 5G, EVs), and finally reach the highest level to artificial intelligence and cognitive computing (SC-5).

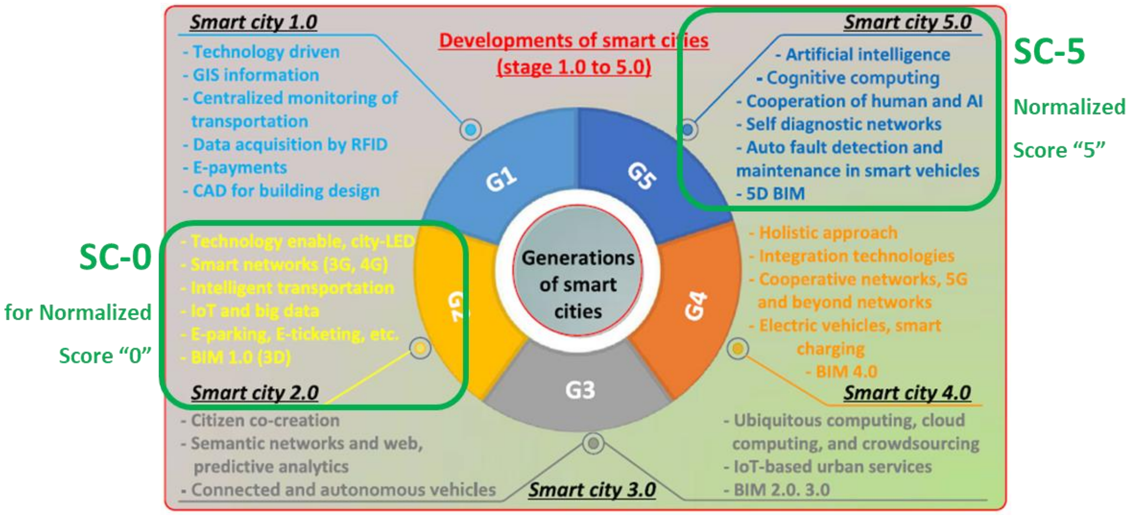

Figure 15. Main stages of a smart city (Khan et al. 2022).

The score for smart cities is defined using qualitative criteria that converts the different stage of a smart city according to the normalization concept used in the CESBA MED sustainability assessment and rating system (Balaras et al. 2019). The smart city indicator is assigned a score of “0” that corresponds to the first stage of a smart city (SC-0) and is reaches the highest stage of a smart city (SC-5) that is assigned to a score of “+5”.

The relevant smart city stages that correspond to the lower (“0) and upper (“1”) limits of the normalized score are defined adapting the concept presented by (Khan et al. 2022), based on the expert opinion and assessment of qualitative criteria, along the following lines:

- **SC-0** for a base score “0”: introduce smart technologies that are explicitly developed by local or central government agencies to handle at least one category and indicator under the issues of energy (e.g. low energy use for public lighting using technology enable LED lamps, or smart energy meters), emissions (e.g. real-time data monitoring of GHG emissions), natural resources (e.g. real-time data monitoring of water consumption or waste production), environment (e.g. real-time data monitoring of ambient air quality), and social aspects (e.g. transportation with smart public services or eTicketing or eParking or communication services with smart networks 3G or 4G) in consultation with citizens.
- **SC-5** for an upper score “5”: ideal cooperation between AI systems and citizens in order to balance all major life and social activities, balancing conflicting interests among the city stakeholders. All city services utilize real-time data and learn from historic data to make better estimates and more accurate projections, accounting for possible preferences and constraints, striving towards ‘‘consensus’’ by optimizing the various services, monitoring and assessing their effectiveness, to meet the needs and expectations of the citizens.

4. Conclusions

The technological advances and digitalization era of the construction sector are reforming and advancing the entire chain of design, construction, operation and demolition (Figure 16). The efforts are widely based on data acquisition utilizing the high technological readiness of sensors by expanding their use in new buildings and focus on their integration in existing buildings, and the fast developing Internet of Things (IoT) with wider adoption in the built environment.

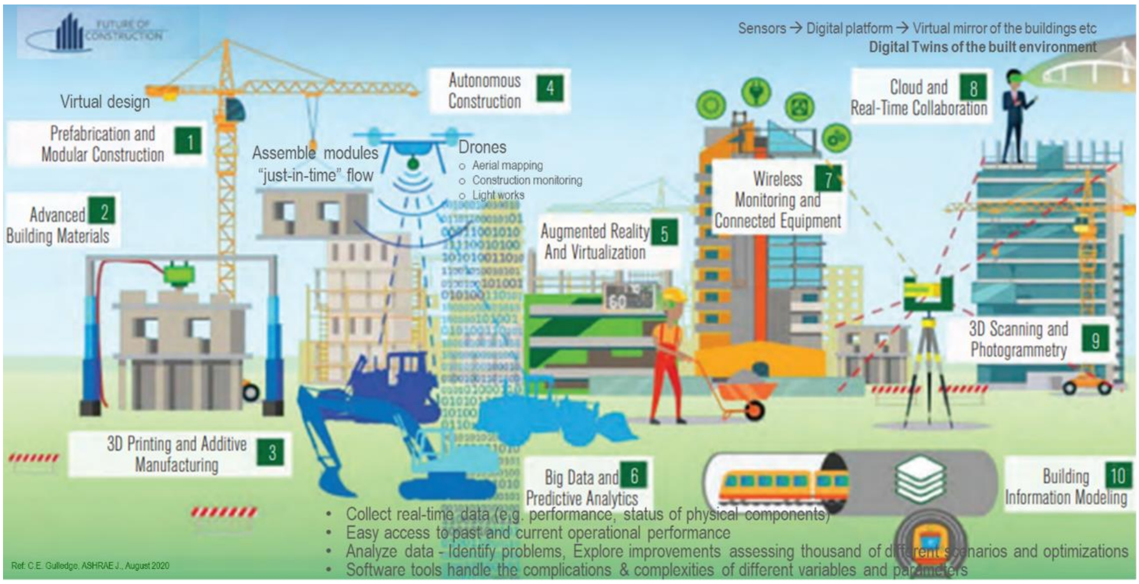

Figure 16. Digitalization in the construction sector (Adapted from Gulledge 2020).

For buildings, a common EU methodology for **rating smart readiness of buildings** or building units has been developed and is becoming an integral part of EPBD and the EU efforts towards the decarbonisation of the buildings sector. Building smartness refers to the building's ability to collect, process, translate, communicate and act in an optimum manner to variable operating conditions for the buildings as they relate to the:

- needs from the occupants,
- operating conditions of the technical installations,
- outdoor environment, including weather conditions and energy grids.

The **smart readiness indicator (SRI)** assesses buildings in their ability to:

- Optimize energy efficiency and energy use,
- Adapt their operation to the needs of the occupant,
- Adapt to signals from the grid (i.e. demand response and energy flexibility).

The SRI was adopted by EPBD in 2018 and its subsequent regulations, triggering the voluntary implementation of national test phases by several EU Member States. Implementation may target the entire building stock or specific building categories. The scheme is very well supported by various resources including an assessment package with a calculation sheet that is supported by a practical guide, and training material.[6] Considering that the SRI concept has advanced and matured to a common EU scheme for rating the building smartness, it can be integrated as a key performance indicator (KPI) in the enhanced concept of the CESBA MED sustainability assessment method that is developed for the Sustainable MED Cities.

The **smart city** model is a booming concept aiming to support cities to best use digital and other technological advances to serve their citizens by improving living conditions, environment, economy, society and governance, among others. Smart buildings constitute an integral element of this model. Furthermore, the model includes numerous sustainability indicators that utilize IoT and digital technologies to further advance various activities for energy, emissions, water, environment, waste, transportation, communication, city services, etc. Progressively, the “smart city” term is evolving to a “smart sustainable city” in order to keep the sustainability priorities in focus, while enhancing the city smartness.

[6] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-implementation_en

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