SUSTAINABLE DEVELOPMENT OF SMART CITIES BASED ON INFORMATION TECHNOLOGY AND EDUCATION[1]

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ABSTRACT: Cities have become much more complex, and public agencies are facing increasing challenges to provide efficient and inclusive services to the community. Cities are highly dependent on civil infrastructure and the technologies adopted for the management of public services including transportation, energy, security, water resources, first aid, and supply chain systems. The Smart City concept is interdisciplinary in nature and represents a new way of managing civil infrastructure by identifying problems with the support of advanced technologies. Within this concept, it is necessary to model various scenarios and analyze potential outcomes to seek the best solution for the situations raised. However, the technological components are insufficient by themselves if they do not allow interaction among the parties involved in the management process. In this context, Building Information Modeling (BIM) is a tool that can improve collaboration and communication among the parties involved in the management of civil infrastructure in a city. This article describes a humanistic concept of a Smart City with emphasis on the quality of life and the role of education in its development and sustainability, integrating modern technology for an efficient interaction of health, transportation, public safety, energy, building management subsystems, among others. These interconnected subsystems must provide the services to sustain the quality of life of citizens. In this humanistic approach, practice of civic values has a fundamental role in the responsible use of resources and technological tools to transform a city into a smart one.

Keywords: BIM, Humanistic Education, Infrastructure Management, Smart City

DESARROLLO SOSTENIBLE DE CIUDADES INTELIGENTES BASADO EN TECNOLOGÍAS DE LA INFORMACIÓN Y EDUCACIÓN

RESUMEN: Las ciudades se han vuelto mucho más complejas y las agencias públicas enfrentan desafíos cada vez mayores para brindar servicios eficientes e inclusivos a la comunidad. Las ciudades dependen en gran medida del desarrollo de infraestructura civil y de las tecnologías adoptadas para la gestión integrada de los servicios públicos de transporte, energía, seguridad, recursos hídricos, primeros auxilios, y sistemas en la cadena de suministros. El concepto de Ciudad Inteligente es de naturaleza interdisciplinaria y representa una nueva manera de gestionar la infraestructura civil identificando problemas con el apoyo de tecnologías de avanzada. Dentro de este concepto, es necesario modelar diversos escenarios y analizar posibles resultados en busca de la mejor solución a las situaciones planteadas. Sin embargo, los componentes tecnológicos son insuficientes por sí solos si es que no permiten la interacción entre las partes involucradas en el proceso de gestión. En este contexto, el Modelo de Información de Construcción (BIM, por sus siglas en inglés) es una herramienta que puede mejorar la colaboración y comunicación entre las partes involucradas en el proceso de gestión de la infraestructura civil en una ciudad. Este artículo describe una concepción humanística de la Ciudad Inteligente con énfasis en la calidad de vida y el rol de la educación en su desarrollo y sostenimiento, integrando tecnología moderna para una interacción eficiente de los subsistemas de salud, transporte, seguridad pública, energía, gestión de edificios, entre otros. Estos subsistemas interconectados deben proporcionar los servicios para sostener la calidad de vida de los ciudadanos. En este enfoque humanista, la práctica de valores cívicos tiene un rol fundamental en el uso responsable de los recursos y herramientas tecnológicas apropiadas para transformar una ciudad en inteligente.

Palabras clave: BIM, Educación Humanística, Gestión de Infraestructura, Ciudad Inteligente

[1] Article received on February 22, 2023 and accepted for publication on April 12, 2023.
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INTRODUCTION

The expression "Smart City" appeared in the 1990s and there are several definitions to describe its multiple aspects. In all these definitions, it is mentioned the term "Information and Communication Technology" (ICT) for the citizens to participate in management processes towards the improvement of public services. It promotes the development of knowledge networks that support economic and social development and emphasizes the integration of technology to build a living environment that fosters the interaction of people through interconnected virtual platforms. Within this general concept are the ICT components adopted in urban areas. Therefore, Smart Cities are defined based on the level of the interaction between civil infrastructure service systems and human-social development and ICTs by the hardware and software components.

The technological components and supporting tools for civil infrastructure are insufficient by themselves for the development of a Smart City. It is essential to consider the expected results when investing in these technologies. A Smart City must be dynamic with the ability to innovate, reorganize, and adapt to changing conditions. It should provide a living environment where all citizens are engaged with those who make decisions and be empowered to contribute overcome problems towards the development of healthier and safer neighborhoods.

This article emphasizes the humanistic aspect of a Smart City focusing on the quality of life and the role of education in development and sustainability. In this view, practice of civic values has a fundamental role in the responsible use of resources and technological tools to transform a city into a smart one. Respect for nature, learning to live together with solidarity, citizen identity, and value of local culture are pillars to build the foundations of a Smart City. The connection between these pillars with the integration of modern technology should lead to an efficient interaction of public services including health, transportation, public safety, energy, and building management subsystems among others. As shown in Figure 1, this interaction should result on equitable and sustainable socio-economic developed communities fostering the well-being of the citizens.

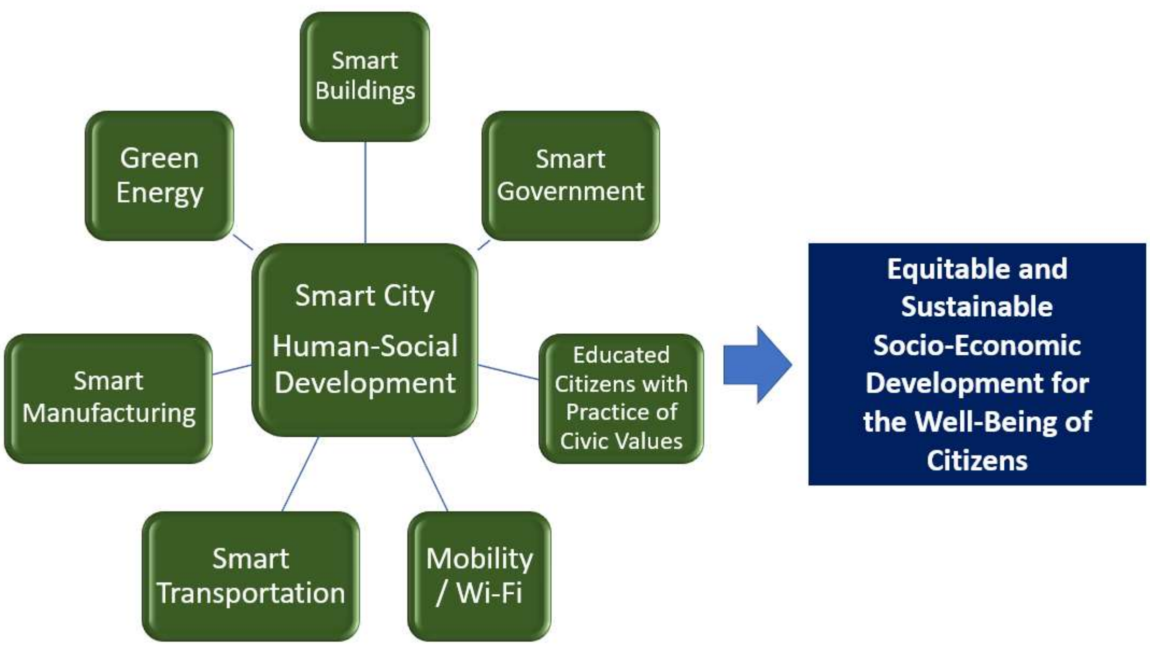

Figure 1: Humanistic centered development approach of a Smart City.

DEVELOPMENT OF SMART CITIES

There are many trends that have led to the rise of smart cities, one of which begins with the rapid urbanization of the world's population. Rural to urban migration began with the agricultural and industrial revolution in the late 18th century. Today, more than 50 percent of the world's population lives in cities. By 2050, it is projected that nearly 70 percent of the world's population, equivalent to more than six billion people, will live in urban areas (United Nations, 2018). This critical mass of people has laid the groundwork for the rise of smart cities.

To provide solutions to the complex problems faced by the cities, it is necessary to articulate multiple subsystems using appropriate technologies while building strong knowledge management networks. The main challenge in the development of a Smart City is to integrate knowledge in order to address present and future needs. Linear, disjointed, fragmented approaches have been used to manage a city while new innovative approaches are required to provide citizens with greater capacity to overcome complex challenges.

The development of a Smart City requires the efficient interaction of multiple subsystems including transportation, citizen security, energy, building management, among others. These interconnected subsystems must provide the necessary services to sustain the quality of life of the citizens. For this development, it is necessary to establish generic and specific objectives. Generic objectives support the identity of civil infrastructure, that is, its own history, culture, environment, or aesthetics. The specific objectives are related to the optimization of energy consumption, the improvement of air quality, the reduction of noise, and the regulation of transport systems to mention some examples (Chang, 2019).

The use of the information collected in each phase of the life cycle of infrastructure projects is complex (Boorman Et al., 2018). Digital tools, such as computer-aided design (CAD) and computer-aided engineering (CAE), have been traditionally used to design, build, and operate civil infrastructure (Czmoch and Pakala, 2014). More recently, one of the ICTs with great potential is Building Information Modeling (BIM). BIM describes the process of creating digital building models for operation and maintenance over the entire project life cycle (Boorman Et al., 2018).

In BIM, data are gathered from the design and construction phases and stored in a visual virtual database. Any change made to the model is immediately reflected in the database (Blanco and Chen, 2018). At the design phase, project alternatives are evaluated by visualizing geometric and geographic information to analyze spatial relationships. Design options are optimized with additional labor and material cost information. In the construction phase, the building process is simulated and it is later used to monitor the work progress. Digital data can maintain civil infrastructure information updated over the entire life cycle.

In practice, the methodology to develop a Smart City using support tools, such as BIM technology, involves several stages:

1. Establish generic and specific multidimensional objectives.
2. Analyze the local context and the interdependence of the factors that influence the development of the Smart City.
3. Design a conceptual management model adapted to local conditions.
4. Select support technology tools for the implementation of the smart city conceptual model.
5. Develop a program of activities and formulate short, medium, and long-term budgets for the implementation of the conceptual model with the support of technological tools.

6. Implement a program of activities including a plan to collect information for later evaluation of the results.
7. Provide feedback based on the results of the implementation to periodically refine the use of technological support tools.

It should be emphasized the importance of understanding the aspects that define the multidimensional character of a Smart City, as well as adapting them to the local culture in order to select appropriate technological tools to implement the conceptual model efficiently. Figure 2 shows examples of BIM applications for a Smart City over the life cycle.

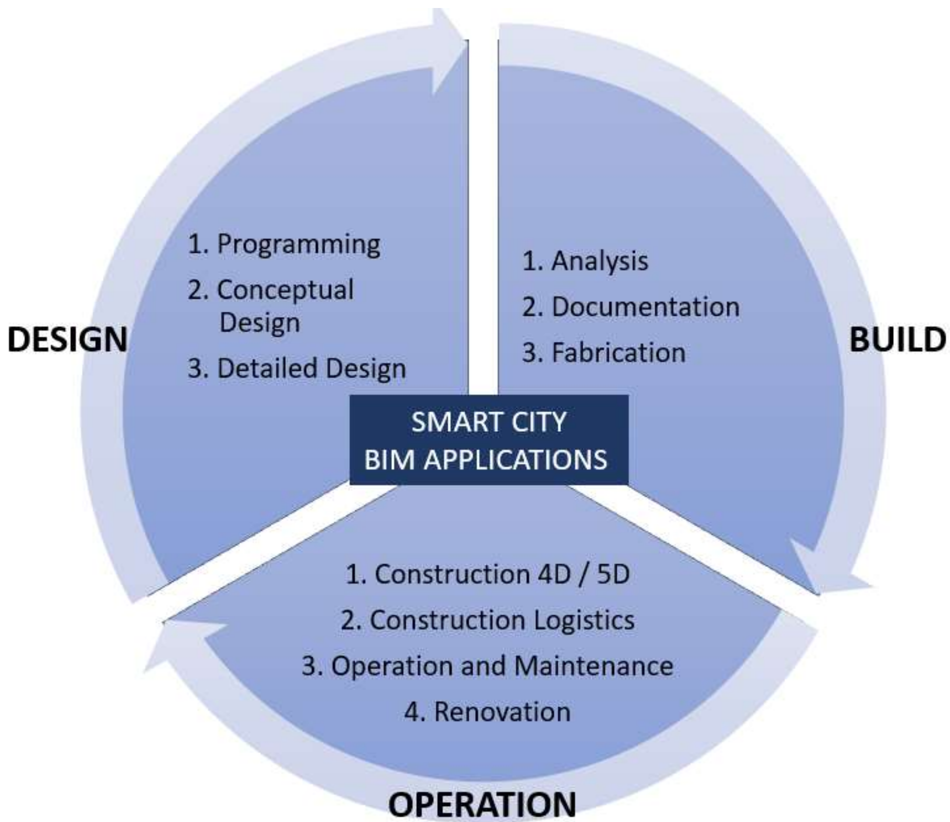

Figure 2: BIM applications over the life cycle of civil infrastructure.

In the next sections, the multidimensional aspects to characterize a Smart City are described, then it is explained how BIM technology could be integrated to provide support for the implementation of the Smart City conceptual model.

MULTIDIMENSIONAL ASPECTS OF A SMART CITY

Cities have high complexity in their function and there are multidimensional aspects in constant change and transformation. The interactions and retroactions of these multidimensional aspects generate new and unpredictable scenarios. Cities are "Systems that contain adaptive components and capabilities that allow systems to change and evolve over time in response to feedback and changes in the system context. Complex adaptive systems have memory, so past experiences can shape future behavior, they have multiple modes of behavior, the ability to transform, and they have dynamic resilience." (Sellberg et al., 2021). Figure 3 shows the interaction of multidimensional main aspects or dimensions of Smart Cities.

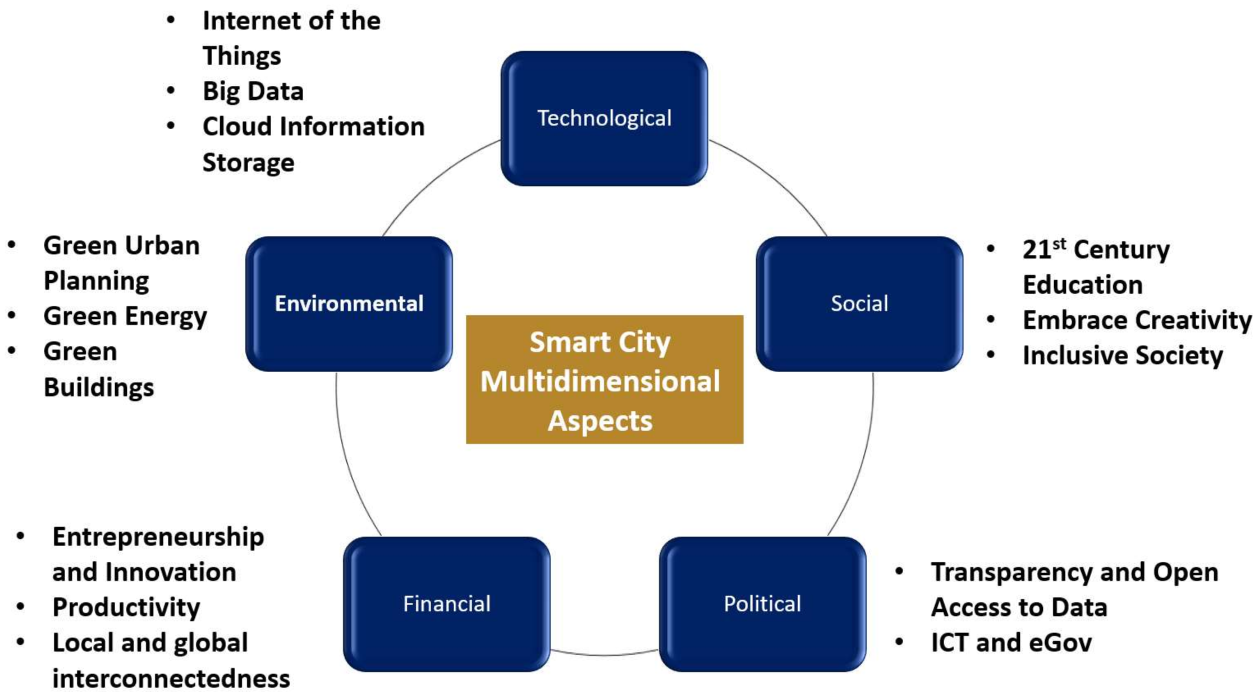

Figure 3: Multidimensional main aspects or dimensions of a Smart City.

Environmental: This aspect is related to the importance of the "responsibility" that people should have for our natural environment. This aspect has led to a growing demand for carbon neutral power supply systems and guidelines for green urban planning of civil infrastructure (e.g. Green Buildings). That is, replacing fossil fuels with wind, solar, and geothermal green energy more friendly alternatives to our physical environment (e.g. automated climate control, environmentally friendly materials). It also involves modifying job habits and working environments (e.g. virtual meetings, telecommuting).

Financial: The globalization of the world economy and the rapid increase in quality demands on the "standard of living" have influenced the rise of smart cities. While it is true that developed countries are constantly pushing the frontiers of innovation, they are often hampered or limited by out-of-date infrastructure systems, higher salaries, and social systems with greater coverage (e.g. insurance rates, retirement costs). While cities in developed countries are adapting innovative smart city technologies (e.g. synchronizing street signs), many cities in developing countries are building smart cities from scratch. Emphasis should be given to fostering entrepreneurship and innovation to increase productivity by improving local and global interconnectedness,

Political: Citizens demand more transparency and accountability from local governments. Governments should provide policies to regulate the implementation of advanced technologies while considering economic, environmental, and social benefits. Policies should regulate data access, data management, and usage of real-time applications. Transparency and open access to data with the implementation of appropriate Information Technology Tools and electronic government platforms (eGov) should facilitate the management processes.

Social: Technological advances have led to significant changes in our social life. An increasingly interconnected world with mobile smartphones and virtual tools residing in the "cloud" has resulted in a mobile workforce that conducts work from anywhere at any time. At the same time, these advances have led to increased concerns about privacy, security, and data integrity. In addition, societal expectations also demand a real-time response. Therefore, finding a balance between work and personal life has become harder. 21st education should consider all these factors while encouraging to embrace creativity and tolerance towards the development of an inclusive society.

Technological: Rapid decrease in the costs of communications technology has led to the development of the "Internet of the Things" and "Big Data" to store massive information in a virtual cloud. Big data is a term that describes the large volume of data, structured and unstructured, that is transmitted continuously. Millions of sensors, interconnected by software and hardware, connect civil infrastructure with users. Examples include solar energy and integrated control systems adopted in buildings; smart grid power transmission and sewage network systems; automated tolls in transportation systems; and real-time route data for public transportation.

Big Data can be analyzed to obtain insights that should lead to better management decisions to support the development of a Smart City. Their use is becoming common practice in organizations to improve their efficiency by adopting better strategies as a result of the data analyses.

Figure 4 shows that big data applications for Smart Cities require to consider the veracity of the data, volumen of information, velocity of transfering this information, variety of unstructure data from different subsystems, and the value or cost of data processing.

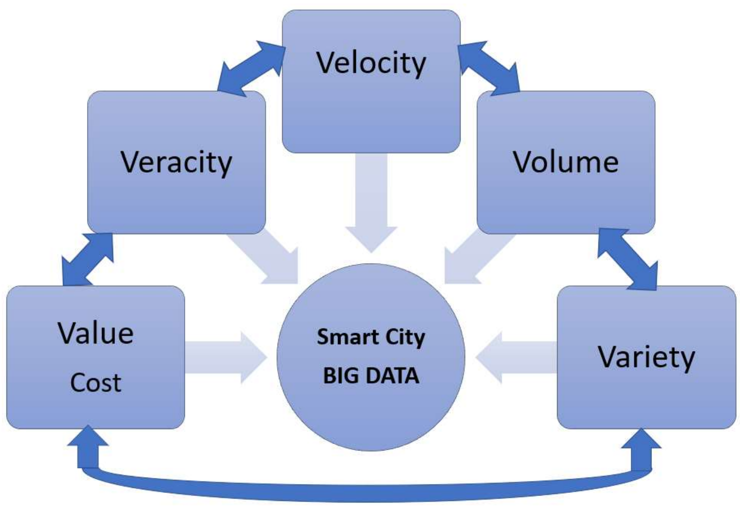

Figure 4: Big data requirements for Smart City applications.

The BIM model is essential to work virtually, carrying out simulations that, accompanied by the Big Data tool, allow organizations to be fully aware of all their resources, giving them the ability to respond to any situation quickly and efficiently. Through a BIM supported by Big Data, organizations are able to:

- Know in real time the use of resources to optimize energy consumption.
- Optimize designs by learning about the performance of civil infrastructure.
- Predict behavior and risk situations to alert users.
- Supervise actions through virtually integrated platforms for monitoring the response of different management agents.
- Simulate proposals and evaluate management actions before implementing them.
- Provide technical resources to record and retrieve information from a trusted source.
- Integrate more complex systems that are required to develop and sustain a Smart City.

BIM TECHNOLOGIES FOR SMART CITIES

Various disciplines are involved in the design, construction, and operation of a project (Borman Et al., 2018). All parties involved in the life cycle of a project - owner, designer, contractor, subcontractor, and supplier - should collaborate to build civil infrastructure cost effectively. Many projects lack technical components to support a collaborative management approach. A collaborative approach to manage civil infrastructure emerges as the cornerstone to integrate information across the strategic, network, and project management levels. To coordinate activities and efficiently integrate different management levels, it is necessary to use advanced technological tools such as BIM.

ISO 19650 (ISO, 2020) describes a Building Information Model as a shared digital representation of an information model to facilitate the design, construction, and management. BIM provides a complete digital representation of a project including dimensions, spatial relationships, geographic information, quantities, and properties of construction components. Additional information includes execution time, cost of labor, material, and equipment (Azhar, 2011). Multidimensional BIM tools can be classified into categories composed of three dimensions (3D), four dimensions (4D), five dimensions (5D), six dimensions (6D) and seven dimensions (7D). As the number of dimensions increases, more data and models should be integrated (Gourlis and Kovacic, 2017).

The maturity level of BIM in an organization is established by the degree of integration of the team working around a single model to collect, store, and extract information about the project. Level 0 describes the traditional 2D work practice based on sharing drawings on paper. Level 1 includes the combination of 3D virtual models and 2D drawings. Data can be shared by exchanging individual files using ISO standards. At level 2, BIM models created by various disciplines are combined to check for conflicts or discrepancies. Level 3 describes the integration of BIM models for the entire life cycle of an infrastructure project. All data can be shared through a central platform. Project data is managed using cloud services, so that the information can be managed through the entire life cycle of a project.

Information Requirements for the Use of BIM

The ISO 19650 (ISO, 2020) series is based on the British standards BS 1192-2 (Richards, 2010) and PAS 1192 (PAS, 2014). It summarizes the approach to work with BIM. Being the collecting and managing project information the main objectives of the BIM methodology, it is necessary to establish the information requirements at the different stages of the life cycle, and to delimit both factors in an efficient, effective, and timely manner.

ISO 19650 provides a set of specifications about what information is to be produced, when it is to be produced, its method of production, and its recipient. The information requirements are initially defined by the contracting party, and they may be extended by establishing particular requirements. It is important that the contracting party explains the main reasons why the information is required for a better understanding of the collaborative work to be carried out. All the participants have a level of responsibility in the definition of the following information requirements:

- OIR: Information Requirements of the Organization related to its objectives.
- PIR: Project Information Requirements related to its development.
- AIR: Information Requirements of the Infrastructure Project as related to its operation.
- EIR: Information Exchange Requirements between two parties subjected to a contract.

The collaborative approach using BIM for the management of civil infrastructure information is aimed at improving the standards used for the evaluation of investments, contracting and formulation of public budgets. BIM deliverables are classified in:

- PIM: Project Information Model as related to the development phase.
- AIM: Information Model of the Infrastructure Project as related to the operation phase.

It is common practice to begin with the end of the process when establishing the use of BIM, because the operational and management stage usually counts as the highest percentage of expenses in the service life of an asset.

Benefits of BIM towards Sustainable Smart Cities

Infrastructure management is a complex decision-making process due to many disciplines involved in the process, multiple objectives, and different perspectives. BIM can improve the collaboration and communication between the parties involved in this process. Having an accurate BIM, developed with the collaboration of all interested parties (client, designer, builder, operation manager) from the earliest stages of a project life cycle, is fundamental for the development of a Smart City. For example, BIM can be used in the evaluation of design alternatives, activity scheduling, cost estimation, material selection, prefabrication opportunities, placement on site, and life cycle cost analysis.

BIM should add value in the development and management of civil infrastructure by offering solid, coherent, and useful information that should lead to the following expected results:

- A clear definition of the information required to manage civil infrastructure, as well as the methods, processes, deadlines, and protocols required to achieve generic and specific multidimensional objectives of a Smart City.

- Quantity and quality of the information to meet the requirements defined in the conceptual model of a Smart City.

- Efficient and effective transfer of information among the participants involved at each stage of the life cycle of civil infrastructure.

Among the benefits of using BIM is the generation of a digital twin that is updated dynamically throughout the life cycle of a project. BIM allows to carry out simulations at the planning, design, construction, and management stages. A digital twin refers to a digital replica of physical assets, processes, people, places, systems, and devices that can be used for various purposes.

A digital representation provides the elements and dynamics of how a device works and performs as part of the Internet of Things (IoT) throughout its life cycle. In the first place, the connection created by a digital twin between the physical model and the virtual model or virtual counterpart is needed. This connection is established by generating data in real time through the use of sensors. With a digital model, an organization can estimate costs and analyze existing conditions at the planning stage. At the design stage, interference detection, energy analysis, structural analysis, environmental evaluation, and others can be performed. Simulation of construction processes, digital manufacturing to build models to produce as-built documents can be carried out at the construction stage. Finally, maintenance and risk control strategies can be established and implemented at the management stage.

ROLE OF EDUCATION TO SUSTAIN SMART CITIES

Among the goals of the United Nations is the development of cities that are safe, resilient, and sustainable. Other goals are to quality education and to develop industry through innovative infrastructure solutions. These objectives are related and require information technology to achieve them (United Nations, 2022).

A Smart City uses the advances of technology as a means to care for and sustain the quality of life. However, it is required to build the necessary knowledge through the implementation of educational programs. To educate is to create, carry out, and validate a particular form of coexistence. This is performed through a dialogue to harmonize thoughts with emotions. In this sense, the preservation of cultural and social values should be Smart City foundation. This also means providing an education that promotes respect for natural resources with citizens socially and ecologically responsible for their actions. In this educational process, there are three main challenges:

The first challenge is to develop a knowledge structure that is:

- How do people build knowledge?
- How does knowledge build people?
- How does knowledge build the patterns of the mind?
- How do we build cities and how do cities build us?

The second challenge is to overcome the reductionist and fragmented vision of the educational traditional system. Education should not be reduced to formal areas, education through life experience is essential. In this sense, it is critical to provide public spaces and interactive knowledge centers to support effective learning.

The third challenge is community education focused on building values of trust, harmony, and reciprocity. Solidarity and tolerance to face uncertainties while overcoming problems of poverty, violence, crime, hunger, and climate adaptability among others.

To address these challenges, the traditional dominant thought approach that isolates and separates knowledge content must be replaced by a complex thought approach that unites and distinguishes knowledge from different sources. Disjunctive and reducing thinking approaches must be replaced in the educational process by a "complex thinking" approach that fosters cooperative actions.

The characteristics of a dominant thought knowledge approach are summarized as:

- Fragmented perception of the world.
- Absolute truths.
- Static vision
- Linear language in the description of the world.
- Controller

The characteristics of a complex thought knowledge approach are summarized as:

- Complex perception of the world.
- Uncertainty.
- Dynamic vision
- In the description of the world, use a circular language.
- Participatory and resilient

From an ethical perspective, educational efforts in the planning and development stages of a city should allow the implementation of a more rational usage of existing resources. This effort should contribute to the development of equitable and sustainable socio-economic communities. It involves using technical knowledge to sustain the quality of life of the people who live in the city. The main purpose in the development of a city should be the well-being of citizens. In this context, universities have the duty of providing high quality education to address the inclusive needs of a community with respect and dignity.

CONCLUSIONS

1. The development of a Smart City is interdisciplinary in nature and requires the integration of knowledge about cultural identity and social community values with innovative technologies, supported by an education plan towards the development of sustainable civil infrastructure solutions to address the inclusive needs of the citizens.

2. Smart cities must be able to innovate, reorganize, and adapt to environmental, economic, and social dynamic changes. Citizens must be actively engaged with local governments to solve problems that affect the development of healthier living environments and safer neighborhoods.

3. It is essential to understand the multidimensional aspects that define the character of a Smart City: environmental, financial, political, social, and technological. These aspects must be adapted to the local culture and appropriate technological tools should be selected accordingly for managing civil infrastructure. The alignment of strategies, plans, and contracting acquisitions with public services that address the needs of citizens should be the ultimate purpose of a Smart City.

4. BIM technology can be fundamental in the development of a Smart City. Defining what a BIM is, objectives and uses, as well as the level of development (LOD) or level of information (LOI), allows better understanding of its potential as a support tool for managing civil urban infrastructure.

5. The use of BIM as a support tool at different stages of the infrastructure life cycle involves the need for a common virtual environment from the beginning. The best time to introduce BIM is at the planning stage. At this stage, there will be the greatest probability of positively influencing the quality of services provided by civil infrastructure to the citizens.

6. A digital twin of civil infrastructure is considered an important collaboration tool. Adequate and timely specification of digital twin models for a city allow both to receive and to generate large volumes of information that becomes big data. This information is useful to carry out simulations of potential threats in order to alert the citizens and prepare them to respond to these situations.

7. The success in the development of a Smart City, administrative or technological, lies mainly in the human factor. BIM, as a collaborative tool, does not escape this reality. It is very important to educate citizens and to train local government staff in the development and implementation of efficient management processes.

8. It is necessary to change the fragmented, linear, reductionist thinking traditional approach by an integrative complex thought innovative knowledge approach. This innovative knowledge approach should foster active participation of the citizens in a dynamic complex environment towards better informed management decisions in local governments.

9. Education is required to build values with respect for cultural identity and social inclusiveness as the foundation of a Smart City. In this humanistic approach, the practice of civic values is fundamental for a responsible usage of resources and technological tools. In this sense, universities have the fundamental role of providing high quality education to address the inclusive needs of a community.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Dr. Iván Rodríguez Chávez, President of the Universidad Ricardo Palma, to the research project titled "Sustainable and Resilient Smart Cities". In addition, our special appreciation to the International Society for Maintenance and Rehabilitation of Transport Infrastructures (iSMARTI) and the Instituto de Construcción y Gerencia (ICG) for hosting the 5th International Conference on Transportation Infrastructures in August 2022 (V ICTI). Presentations related to the content of this article were delivered at V ICTI. This article merges concepts and content from two presentations: "Planning and Development of Smart Cities Using BIM Tools: An Integrated Management Approach" and "Education, Sustainability, and Development of Smart Cities". For additional information, please refer to the conference proceedings. It is noted that some extracts were modified and translated into English from the article titled: "Planificación y Desarrollo de Ciudades Inteligentes Utilizando Herramientas BIM: Un Enfoque Integral de Gestión" by C. Chang and M. Vélez Canchanya, published on the Journal of Engineering Profiles by the Universidad Ricardo Palma in December 2021 (DOI: https://doi.org/10.31381/perfiles_ingenieria.v17i17.4575).

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