Journal of Ubiquitous Systems & Pervasive Networks
Volume 3, No. 1 (2011) pp. 00-00

Design and Study of a Digital Energy Building: Case of Morocco

Abdelali Agouzoul[a*], Mohamed Tabaa[a], Badr Chegari[c], Meryem Mhenni[a], Emmanuel Simeu[c], Abbas Dandache[b], Karim Alami[a]

[a]*LPRI Lab, EMSI Casablanca, Morocco*
[b]*LGIPM, Lorraine University, France*
[c]*Univ. Grenoble Alpes, CNRS, Grenoble INP, TIMA, 38000 Grenoble, France*

Abstract

In the industrial revolution that followed, the aim of the industry is not only to improve and meet its urgent needs, but also to improve the standard of living of society and make life easier for consumers. Therefore, economic growth must always be closely linked to the industrial revolution. The medical industry, energy conservation and, in particular, production technologies will be transformed through new value chain models. Globalization, urbanization, vital changes and the energy transformation are all shifting forces that assess the dynamics of technology to better identify solutions in the moving world. In recent years, successive revolutions have made remarkable contributions to a person's quality of life, safety, industrial economy, comfort and health. This work aims to improve the energy consumption of the building. To achieve this goal, digital twins were created to faithfully reflect the behavior and characteristics of future or current buildings. To replicate copies of future or existing buildings, we chose to use Autodesk REVIT solution to meet some limitations. These have a great influence on the energy behavior of the building.

Keywords: *Digital twin, Building, Energy Management, Smart Cities, industry of the future, IoT;*

1. Introduction

The digital twin, collaborative robots, data processing algorithms, energy challenges and advanced technological tools must collaborate to re-found the industrial model. They represent an opportunity to improve the attractiveness of various industrial applications. Some examples of the impact of these developments on the national economy show that industrial modernization and digitization are making an important and lasting contribution to economic improvement. The Chinese and Japanese models illustrate the virtues of this industry of the future on their economic strategy [1, 2 and 3].

However, today's digital compagnies revolution is a milestone in the development of industries as well as the economy. This industrial digital transformation was initiated by the German government through the fourth industrial revolution known as "Industry 4.0" or "Smart Manufacturing" [4, 5]. This transformation has been the source of inspiration and change for other global initiatives, including the Chinese and Japanese economic forces. This revolution will lead to radical changes not only in systems and processes, but ultimately in management strategies, business models and workforces.

In 2019, the American analyst firm Gartner ranked Digital Twins as a strategic technology trend. The Digital Twin concept is based on the development of multi-physical modeling of a complex system, taking into account the integration of real objects for real-time monitoring [6, 7]. Applications include production infrastructures (factories, rail networks), machine tools, robotic systems and complex components. Today, digital twins are an important element of future industrial development. Through data-driven preventive maintenance strategies, productivity gains, and process optimization, it provides insights into machine behavior and identifies the risk of equipment failure.

In this global context, the electricity sector has focused on the consumption of the main energy sources in urban areas. This forces city planners to rebuild the spirit of the city with the concept of smart energy city. Power generation has undergone several changes over the decades, moving from decentralized to centered generation to move towards distributed generation with the integration of renewable energies. The implementation of renewable energy sources has been considered by governments as an alternative option to the modernization of traditional power plants [8, 9 and 10]. This is due to the increased availability of renewable energy sources and the advantages they offer, including cost effectiveness, inexhaustibility and reduced greenhouse gas emissions [11, 12]. However, the main constraints over renewable energy sources are their intermittency and their management, storage included, to meet the energy balance between the production and the demand [13].

This paper aims to improve the energy consumption of buildings, and to achieve this we have created digital twins that faithfully reflect the behavior and characteristics of future or current buildings. We decided to use the Autodesk REVIT solution to recreate a replica of a future or current building. This allows us to target multiple disciplines that have a significant impact on the energy behavior of a building. The

* Corresponding author. Tel.: +212679552787
E-mail: agouzoulabdelali@gmail.com

DOI: 10.5383/JUSPN.03.01.000

first field is architecture, not only essential for building construction, but also plays a very important role in the energy envelope of the building, which has a great influence on energy demand of the building, we will see this in more detail in the following sections.

The paper will be presented as follows: The second part is to discuss the usefulness of energy management in the building sector by highlighting the energy state of this sector in Morocco. The latest technology on the evolution of digital twins will be the theme for the third part. The discussion of implementing a building energy model will be covered in Part 4. Finally, a conclusion and some perspectives.

Table 1 : Acronyms.

ADEREE	The National Agency for the Development of Renewable Energies and Energy Efficiency
AI	Artificial Intelligence
AMEE	Moroccan Agency for Energy Efficiency
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CFL	Compact Fluorescent Lighting
COP	Coefficient Of Performance
COP 21	Conference Of the Parties 21
DT	Digital Twin
EUI	Energy Use Intensity
HVAC	Heating, Ventilation and Air-Conditioning
HW	Hot Water
IEA	International Energy Agency
IEPs	Independent Electricity Producers
LED	Light Emitting Diode
MASEN	Moroccan Agency for Sustainable Energy
NZEB	Net-Zero Energy Building
ONEE	Office National de l'Electricité et de l'Eau potable
PV	Photovoltaic
WWR	Window-Wall-ratio
Yr	Year

2. Energy trends in Morocco

Morocco is a middle-income country with a population of about 34 million [14]. With these two parameters, Morocco's energy sector will face double challenges: meeting electricity demand and regulating the supply of raw materials. Morocco's energy sector is dominated by the state-owned utility, ONEE. The ONEE acts as the sole purchaser of electricity in the territory. The ONEE acts as the sole purchaser of electricity and produces about 41% of Morocco's electricity in its own power plants, the rest being imported (18%) or purchased from IEPs [15].

According to IEA the contribution of each source in the country's production shows that Morocco relies on more than 80% of its production from non-renewable sources. On the other hand, Morocco is a net importer of energy. Indeed, in 2013, energy imports accounted for about 90% of national energy consumption [16]. Electricity is the major source of consumption of energy imported by the country. This is demonstrated by the fact that until 2000 the country relied significantly on fossil fuels to meet the demand for electricity.

In order to achieve the national renewable energy and energy efficiency targets, several legal reforms have been implemented, namely Law 16-09, 57-09, 13-09 for the creation of ADEREE amended and supplemented by Law 39-16 and operated since 2016 under the AMEE, the creation of MASEN and the standardization of the use of renewable energy in Morocco, respectively. According to this awareness of climate

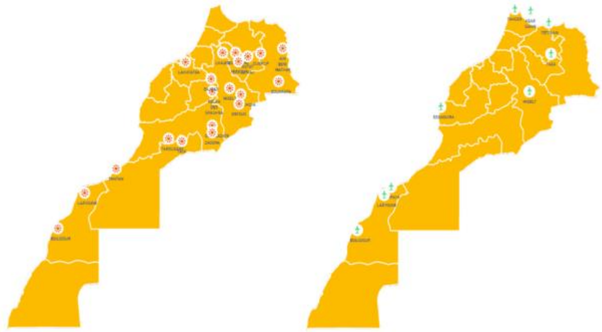

Fig. 1 Solar and wind projects in Morocco.

change, Morocco is committed to keeping global warming below 2 degrees at the 21st session of the United Nations Climate Conference (COP 21) held in Paris in December 2015 and in Marrakech in 2016 for its next session, applicable to all countries. Morocco has a great potential for the exploitation of renewable energy sources, which would help solve two major problems of the country: energy security and climate change and achieve its national objectives including the use of renewable energy and energy efficiency through the obligation of energy audit on industrial buildings following the law n°47-09 [17, 18].

Taking into account all these economic and social changes that Morocco has undergone with the establishment of these laws, the implementation of renewable energies whose sources are intermittent as well as the energy demand that is constantly increasing, the country's electrical network is becoming obsolete. The technological development of energy management systems in the building sector is becoming more and more requested for a better management of the production, distribution and storage of these resources. The usefulness of an energy management system becomes apparent, as it helps minimize energy consumption while optimizing comfort in a building, not to mention the coordination between the energy needs of the final consumers in this sector and the different energy producers, prioritizing the production from renewable sources.

3. Digital Twin

There are several definitions of DT in the literature [19]. In [20], the digital twin is defined as a computational model of an equipment or system that represents all the functional characteristics and links with the actual element. In [21], the authors defined the digital twin as a dynamic model of a real system, which continuously adapts to operational changes based on data and information collected online and can predict the future of the corresponding physical counterpart. In [22], a digital twin is defined as a set of virtual information that fully describes a potential or actual physical output from the micro-atomic to the macro-geometric level. According to [23], a digital twin is a digital representation of a physical element or assembly using integrated simulations and service data. The digital representation contains information from multiple sources throughout the product life cycle. This information is continuously updated and visualized in different ways to predict current and future conditions, both in the design and operational environments, to improve decision making. The authors in [24] show that a digital twin is a virtual instance of a physical system that is continuously updated with performance, maintenance and health status data throughout the life cycle of the physical system.

All these different definitions lead us to differentiate between 3 terms that are similar:

- The first term is the digital model which is described as a digital version of a pre-existing or future physical object, with no automatic exchange of data between the physical object and the digital model.
- The second term is the digital shadow which is defined as the digital representation of an object that has only one direction of data flow: the change in the state of the physical object implies a change in the digital object.
- The third and last term is the digital twin, the difference this time is that the data flow between the existing physical object and the digital object is fully integrated in both directions.

The digital twin should have three main parts [25]: the physical object, its virtual model, and the data and information connections capable of linking the physical and virtual objects together. The later could be achieved through the use of IoT combined with Big Data which gave new opportunities for Smart building [26] as well as Smart building and Cities [27, 28]. In [29 and 30] the authors defined in more detail the theoretical foundations of digital twins applied to industry, and most of the work highlights the following key technologies:

- Modeling: physical and virtual models must describe the main characteristics of the system.
- Connection: the physical and virtual system must be constantly connected. This concept includes data transmission, conversion, storage, protection, etc.
- Advanced data analysis: to obtain information from a database, it must be pre-processed (cleaned and filtered) and exploited by data analysis techniques and artificial intelligence (AI) algorithms.

4. The development of the energy model

The characteristics that interest us in our quest are mainly heat transfer coefficient (U, W/(m². K)), thermal resistance (R, (m². K)/W) and thermal mass (kJ/K) as far as walls and floor are concerned. What influences these values are the number of layers used as well as the constituent materials (tiles, marble, reinforced concrete, wood, thermal and acoustic insulation ...) and their thickness. These specificities influence, in one way or another, the behavior of the thermal envelope of the building. A good thermal insulation avoids us to have thermal bridges between the different rooms, and the one that is the most widespread is the insulation concerning the external walls which are always subject to thermal exchanges between the room and the outside world. This unfortunately leads to an abusive use of HVAC by the inhabitants to achieve their desired thermal comfort, which considerably increases the electrical load consumed by the building.

The choice of construction materials plays a very important role since we can notice that there is a difference in the value of thermal resistances for the two doors (metal and wood). Windows and patio doors have, in addition to the factors seen before, the solar heat gain coefficient and the transmission of visible light. The latter allows us to reduce the energy demand of the building by reducing the electrical load necessary for a good lighting that meets the needs of the inhabitants. The types of lightnings could also reduce significantly the energy needed to meet the visual comfort of habitant, [31] show that it is possible to reduce up to 78% the energy consumption for lightning by using the luminaries with a LED light source instead of CFL. The quality of the glass also has repercussions on the energy demand of the room since it allows a heat transfer between the two different spaces (interior and exterior), without forgetting the noise reduction.

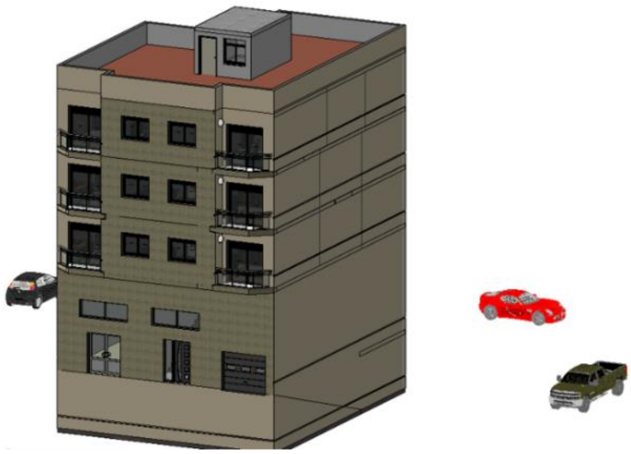

Fig. 2. The proposed model.

This now brings us to our study model which is a building consisting of a garage, a ground floor, three floors and a terrace, as shown in the previous figure, we will see this in more detail in the following parts. We decided to design a R+3 to be able to analyze the impact that each variable can have in interaction with our model, including the number of rooms in each apartment, the characteristics of its walls, windows, doors ..., the location of the apartment (1st,2nd,3rd floor).

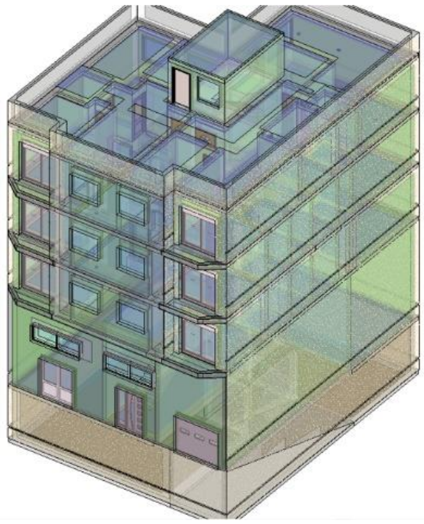

Fig. 3. Energy model on REVIT.

The model shown in Figure 3, presents the energy model. This model is generated using the data and characteristics of the elements constituting our model (walls, floors, doors, windows...), this model is based on the volumes of the rooms, these spaces allow us to set up the areas where the HVAC systems are functional. After the generation of the energy model, a simulation of its performance is available thanks to the simulation in the cloud, which takes into account the data from the energy model and the location of the project, REVIT allows you to specify the exact location of your project and then choose the nearest meteorological site to exploit its data during the simulation. This simulation takes into account the solar radiation, the outside temperature, the location, the operating time of the building (24H/7d, 12H/5d...), the type of building (residential, office, school, hotel...). This is possible using the integration of INSIGHT, in addition to this an Insight plug-in is available to further improve the building's performance by allowing to simulate HVAC systems and choose the zones where these can be active. As well as a simulation of the lighting behavior to achieve visual comfort without excessive consumption of the luminaires.

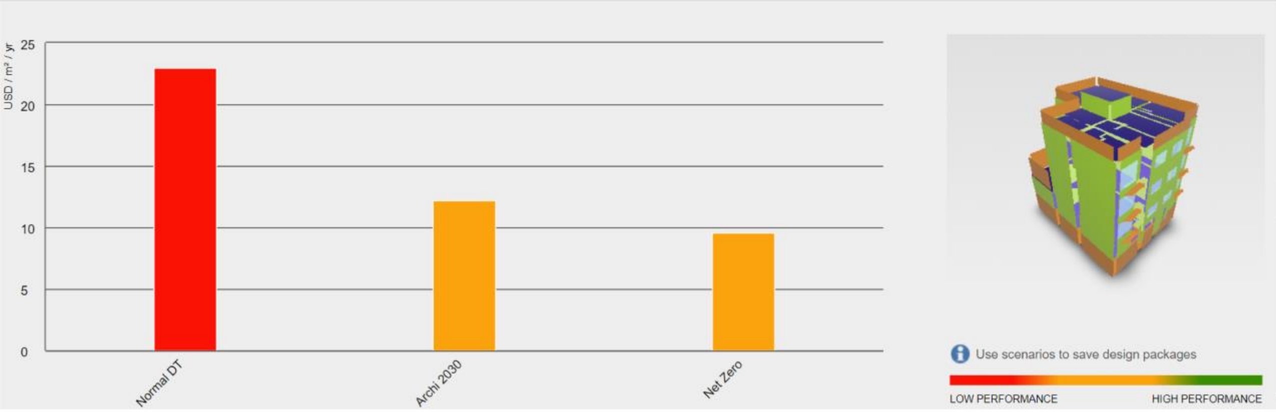

Fig. 4. Comparison between different Insight's proposed scenarios.

The Insight platform provides us with two of the most popular and coveted scenarios (Fig.4.), which are Architecture 2030 and net zero. Figure 4 represents the average cost of the energy consumption, in dollars per square meter per year, of our model under the different scenarios. The first scenario enables us to reduce energy consumption of our homes by approximately half, by acting on the specific features we have discussed previously. The difference with net zero or commonly known as NZEB is that it aims to produce the energy the building needs from renewable energy, such as PV.

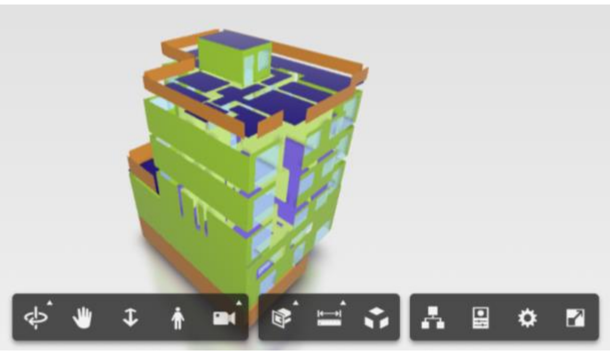

Fig. 5. 3D axonometric view of the model on Insight.

Since the creation of the Insight energy model (Figure 5), the following results (Figure 6) have been obtained based on the selection of materials and components of the model. Figure 7 shows how the design's current performance stacks up against industry benchmarks such as ASHRAE 90.1.

The following platform describes in more detail that the average annual consumption per square meter is derived based on several variables such as: the orientation of the building, the WWR which means the ratio of windows and patio doors to walls, the blinds (window shade) which allow to reduce considerably the need of use of the HVAC, and finally the glazing which also plays an important role in the transfer of heat and light, affecting the energy needs of adjacent rooms. These criteria are verified for each facade of the building (East, West, North and South).

Next is the structure of the wall and terrace, which is directly exposed to the sun. This means significant heat transfer and penetration. This forms thermal bridges and leads to a heat exchanger and conduction of heat to the outside of the room.

Fig. 6. EUI of the model.

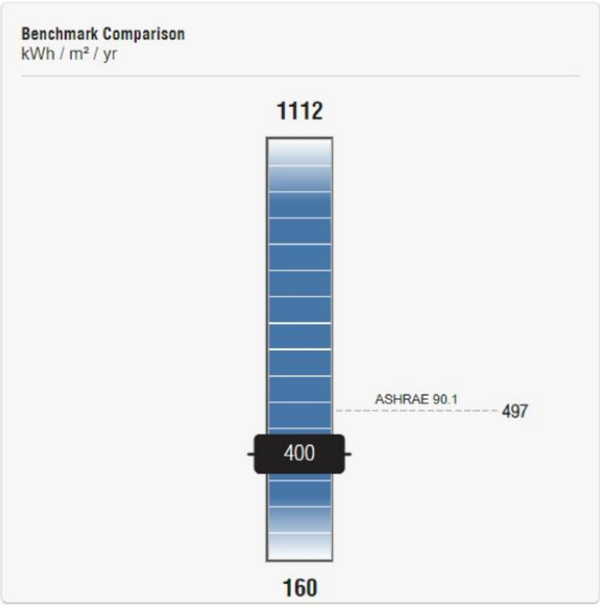

Fig. 7. The Benchmark Comparison.

This is because a building's outside air often enters and ambient air leaks from the building to the outside through cracks in the building's envelope, or the door and window openings.

In addition to this, and as previously explained, the efficiency of the lighting influences the energy demand, as well as the type of control of the light fixtures: whether it is automatic, manual or hybrid. Choosing the right heating, ventilation and air conditioning (HVAC) system has a significant and beneficial impact on the building's energy needs. This often drives up the electricity bill and makes it difficult to effectively meet the needs of residents while using natural resources to produce the energy they need. We can mention, for our case study, that by changing the default HVAC system proposed, which is Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 efficiency, by ASHRAE Packaged Terminal Heat Pump, the energy consumption could be reduced by 133.36 kWh/m²/yr.

The last point to address is the integration of renewable resources such as photovoltaic panels (Fig.8.), to reduce the energy bill of a building. It benefits the economy and the human interests of the population by reducing energy production from non-green resources. This will lead to a reduction in greenhouse gas emissions, not to mention a reduction in the country's bill energy production.

Reaching NZEB is the best scenario we want because it can split and reduce the value of your electric bill to nil. It will allow a self- sufficiency in terms of energy demand. Reducing all factors that can lead to wasted energy and unreasonable demand allows the development of renewable resources. Otherwise, the demand is too high and the PV installation and maintenance process will further complicate the situation and lead to additional costs.

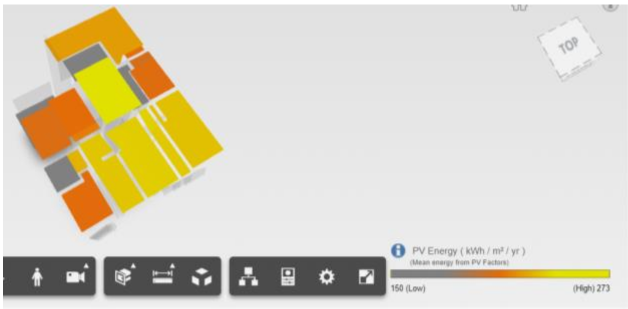

Fig. 8. The possible energy generation intensity of the PVs at the terrace.

5. Conclusion and perspectives

Today, the construction sector offers real growth potential in Africa, especially Morocco. The fight between low-quality housing and infrastructure projects is a strong sign of public sector efforts to build structures that support sustainable economic and social development in land states. This paper presents a new model of digital twins for a future building in Morocco, as far as this sector tends towards a high energy consumption that will have to increase more and more in the future. In terms of outlook, the goal is to incorporate the Net Zero energy as well as the IoT/Cloud model into the building.

References

[1] Nahavandi, Saeid. "Industry 5.0—A human-centric solution." Sustainability 11.16 (2019): 4371.

[2] Sisinni, E., Saifullah, A., Han, S., Jennehag, U., & Gidlund, M. (2018). Industrial internet of things: Challenges, opportunities, and directions. IEEE Transactions on Industrial Informatics, 14(11), 4724-4734.

[3] ZHANG, Chaofeng, DONG, Mianxiong, et OTA, Kaoru. Enabling Computational Intelligence for Green Internet of Things: Data-Driven Adaptation in LPWA Networking. IEEE Computational Intelligence Magazine, 2020, vol. 15, no 1, p. 32-43.

[4] Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology, 94(9-12), 3563-3576.

[5] Özdemir, Vural, and Nezih Hekim. "Birth of industry 5.0: Making sense of big data with artificial intelligence,"the internet of things" and next-generation technology policy." Omics: a journal of integrative biology 22.1 (2018): 65-76.

[6] Dileep, G. (2020). A survey on smart grid technologies and applications. Renewable Energy, 146, 2589-2625.

[7] Mukta, M. Y., Rahman, M. A., Asyhari, A. T., & Bhuiyan, M. Z. A. (2020). IoT for energy efficient green highway lighting systems: Challenges and issues. Journal of Network and Computer Applications, 158, 102575.

[8] Saleem, Y., Crespi, N., Rehmani, M. H., & Copeland, R. (2019). Internet of things-aided smart grid: technologies, architectures, applications, prototypes, and future research directions. IEEE Access, 7, 62962-63003.

[9] Al-Turjman, F., & Abujubbeh, M. (2019). IoT-enabled smart grid via SM: An overview. Future Generation Computer Systems, 96, 579-590.

[10] Grieves, Michael, and John Vickers. "Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems." Transdisciplinary perspectives on complex systems. Springer, Cham, 2017. 85-113.

[11] K. Steinbacher and K. Steinbacher, “Case Study: Morocco,” in Exporting the Energiewende, Springer Fachmedien Wiesbaden, 2019, pp. 187–238.

[12] Data & Statistics - IEA.” [Online]. Available: https://www.iea.org/data-and-statistics/?country=WORLD&fuel=Energy+supply. [Accessed: 26-Dec-2019].

[13] M. El Khaili, M. Redouane, C. Fouhad, et O. Hassan, “Contribution to Multi-Energy Flow Management for Building Energy Hub”, Journal of Ubiquitous Systems and Pervasive Networks, vol. 15, p. 27-34, mars 2021, doi: 10.5383/JUSPN.15.01.004.

[14] El Garouani, D. J. Mulla, S. El Garouani, and J. Knight, “Analysis of urban growth and sprawl from remote sensing data: Case of Fez, Morocco,” Int. J. Sustain. Built Environ., vol. 6, no. 1, pp. 160–169, Jun. 2017.

[15] S. Sahbani, H. Mahmoudi, A. Hasnaoui, and M. Kchikach, “Development Prospect of Smart Grid in Morocco,” in Procedia Computer Science, 2016, vol. 83, pp. 1313–1320.

[16] Boharb et al., “Auditing and analysis of energy consumption of an industrial site in Morocco,” Energy, vol. 101, pp. 332–342, Apr. 2016.

[17] Y. Chen, ‘‘Integrated and intelligent manufacturing: Perspectives and enablers,’’ Engineering, vol. 3, no. 5, pp. 588–595, Oct. 2017.

[18] Z. Liu, N. Meyendorf, and N. Mrad, ‘‘The role of data fusion in predictive maintenance using digital twin,’’ in Proc. Annu. Rev. Prog. Quant. Nondestruct. Eval., Provo, UT, USA, 2018, Art. no. 020023.

[19] Y. Zheng, S. Yang, and H. Cheng, ‘‘An application framework of digital twin and its case study,’’ J. Ambient Intell. Humanized Comput., vol. 10, no. 3, pp. 1141–1153, Jun. 2018.

[20] Z. Liu, N. Meyendorf, and N. Mrad, ‘‘The role of data fusion in predictive maintenance using digital twin,’’ in Proc. Annu. Rev. Prog. Quant. Nondestruct. Eval., Provo, UT, USA, 2018, Art. no. 020023.

[21] Y. Zheng, S. Yang, and H. Cheng, ‘‘An application framework of digital twin and its case study,’’ J. Ambient Intell. Humanized Comput., vol. 10, no. 3, pp. 1141–1153, Jun. 2018.

[22] R. Vrabič, J. A. Erkoyuncu, P. Butala, and R. Roy, ‘‘Digital twins: Understanding the added value of integrated models for through-life engineering services,’’ Procedia Manuf., vol. 16, pp. 139–146, Jan. 2018.

[23] Madni, C. Madni, and S. Lucero, ‘‘Leveraging digital twin technology in model-based systems engineering,’’ Systems, vol. 7, no. 1, p. 7, Jan. 2019.

[24] Grieves, M., et al. 2015. Virtually Intelligent Product Systems: Digital and Physical Twins. In Complex Systems Engineering: Theory and Practice, edited by S. Flumerfelt, et al., 175–200. American Institute of Aeronautics and Astronautics.

[25] Qi, Q., and F. Tao. 2018. “Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison.” IEEE Access 6: 3585–3593. IEEE. doi:10.1109/ACCESS.2018.2793265

[26] A. Daissaoui, A. Boulmakoul, L. Karim, et A. Lbath, “IoT and Big Data Analytics for Smart Buildings: A Survey”, JUSPN, vol. 13, no 1, p. 27-34, oct. 2020, doi: 10.5383/JUSPN.13.01.004.

[27] V. Patel, D. Shah, et N. Doshi, “Emerging Technologies and Applications for Smart Cities”, JUSPN, vol. 15, no 02, p. 19-24, mars 2021, doi: 10.5383/JUSPN.15.02.003.

[28] Tao, F., and Q. Qi. 2019. “Make More Digital Twins.” Nature 573 (7775): 490–491. doi:10.1038/d41586-019-02849-1.

[29] Tao, F., H. Zhang, A. Liu, and A. Y. C. Nee. 2019. “Digital Twin in Industry: State-of-the-Art.” IEEE Transactions on Industrial Informatics 15 (4): 2405–2415. IEEE. doi:10.1109/TII.2018.2873186.

[30] V. Patel, D. Shah, et N. Doshi, “A Comparative of Energy Efficiency of Luminaries for General Lighting for a Residential Building: CFL vs LED”, IJTEE, vol. 14, no 02, p. 125-129, jan. 2018, doi: 10.5383/IJTEE.14.02.006.