Construction 4.0 in Greece: A qualitive evaluation & mapping of the digitalization level

Antonis Rampat[1], Konstantinos Kirytopoulos [2]

[1,2] School of Mechanical Engineering, National Technical University of Athens

mc17064@mail.ntua.gr, kkir@mail.ntua.gr

Abstract
In the era of Industry 4.0, significant transformations have reshaped the production and industrial sectors, yet the construction industry has traditionally lagged behind in technological integration. Although inherently slower to progress, the construction sector has, in its own stride, embraced and adopted some state-of-the-art tools, primarily borrowed from Industry 4.0. Within the context of Greece, there are discernible efforts within the construction sector to align with international conditions. However, a comprehensive understanding of the current state and extent of digitalization remains elusive. This paper aims to shed light on the utilization of advanced Construction 4.0 tools in Greece, identifying specific tools in use, their applications, and the associated benefits and barriers to this transformative process. The research involved 8 interviews and 2 focus groups, involving a total of 13 senior project managers and project directors with decades of experience, working in 6 of the largest construction or project management companies in Greece. The qualitative data gathered from these interviews underwent thorough analysis using the Affinity Diagram Technique, revealing interconnected insights and forming conclusive observations. The findings indicate a prevalent use of BIM and Cloud-Based Management Systems both demonstrating tangible advantages in terms of cost and time reduction. Drones and topographic recording tools like Laser Scanners were common among the surveyed companies, whereas the adoption of Digital Twins and Extended Reality appeared limited and in a nascent stage. A similar limited use was observed about Robotics and Internet of Things. The research underscores that further adoption of those tools, require better or clearer Return on Investment (ROI) metrics and a shift in the mindset within the Greek construction sector. This paper contributes to a nuanced understanding of the current technological landscape in Greek construction, offering material for improvement and future development.

Keywords
Construction 4.0, BIM, Digital Transformation, Greece, Affinity Diagram, Benefits, Barriers,

1. Introduction

With the emergence of the fourth Industrial Revolution, denoted as Industry 4.0, the industrial and manufacturing sectors have undergone a significant technological metamorphosis. In stark contrast, the trajectory of technological evolution within the construction industry diverges markedly. Despite its status as one of the planet's largest revenue generators, considerable differentials exist in its technological maturation vis-à-vis other major industrial domains, but this is not without a reason, as the Construction sector differs significantly from the others (Jepson et al., 2020). Traditionally perceived as among the less technologically sophisticated sectors, construction has embraced the tools and informational technologies emblematic of Industry 4.0 to a lesser extent than its counterparts, including the realms of electronics, mechanical engineering, and industrial production (Zabidin et al., 2020). Nevertheless, the construction sector benefits from the transfer of advanced manufacturing tools on a global scale.

The Greek Construction Sector presently navigates a trajectory of alignment with contemporary technological paradigms on a global scale. Consequently, a meticulous appraisal of the prevailing status quo within Greece's construction domain assumes paramount significance. Such an appraisal is poised to elucidate the sector's developmental trajectory vis-à-vis the global milieu, thereby facilitating informed assessments concerning the potential impetus for further investment in advanced technological infrastructure. At present, there is no comprehensive assessment of the technological progress within the Greek construction industry. The degree of adoption of modern technologies remains undisclosed, and the benefits and obstacles contributing to the current state of affairs are not readily apparent. Consequently, the technological evolution and modernization of the construction market are rendered more arduous and less feasible.

In order to improve and further develop the digitalization of construction industry in Greece, this paper aims to shed light on the utilization of advanced Construction 4.0 technologies in Greece, identifying specific tools in use, their applications, and the associated benefits and barriers to this transformative process.

2. Literature Review

The Literature Review revealed twelve main technologies of the global Construction 4.0 and displayed their state-of-the-art applications. These technologies include BIM, Digital Twins, Internet of Things, Extended Reality, Artificial Intelligence, Robotics, 3D-Printing in Construction (Additive Construction), Drones and Laser Scanners, Off-site Construction, Big Data Analytics, Mobile/Cloud Computing and Blockchain.

BIM is not just a 3D-CAD drawing, but an actual representation of the real components and structures that compose the real project (Azhar et al., 2012). More than digitally depicting a building, it facilitates communication among engineering disciplines as well as construction parties. Thus, BIM is an extremely important tool for the whole project and building operation lifecycle. It is used for time, cost, facility and operations management, planning, safety and many other applications (Biswas et al., 2024) and consists the basis of cooperation with other technologies, which can lead to even more and more advanced applications. An extension of BIM is the Digital Twins technology which enables the construction team to perform simulations (Akanmu et al., 2021), predict errors, energy consumptions, material excess, offer better planning and resource management, material handling and monitoring, support decision making and increase health and safety with simulated trainings (Singh & Kuts, 2022). Internet of Things, Augmented and Virtual Reality are some other technologies that may supplement Digital Twins and provide a range of very useful applications to the construction industry. A lot of them involve increasing health and safety in the construction site (Khurshid et al., 2023), reducing costs by minimizing trial and error, maximizing energy efficiency (Jia et al., 2019). Some other offer better progress monitoring (Ahmed, 2019) and workers' trainings for using machinery or for proper construction site movements (Wang et al., 2018) increasing safety again.

Artificial Intelligence increases automation and reduces the need for human intervention. It is not widely used yet, but has some applications. It can reduce errors, find optimized solutions by simulations and make decisions in every lifecycle phase (Pan & Zhang, 2023). Robotics are either automatic robots specialized for specific jobs or construction machines equipped with sensors like laser scanners and GPS that make them work automatically. The technology, definitely, draws from Industry 3.0 but the interconnection with IoT makes it a central part of Industry 4.0, as well. Robotics can perform different tasks automatically, like bricklaying, floor finishings, welding, etc. Construction 3D-Printing or Additive Construction is a technology like the wide-known 3D-Printing, but with concrete extrusion. It is not widely used and has very specific applications like free form structures, special or lighter buildings (Labonnote et al., 2016). Off-site Construction is a delivery method that uses technology that belongs to the Robotics umbrella but can also support 3D-Prinitng for construction. It has some interesting applications like full structures manufacturing off-site and then installation on-site, such as façade or aluminum frames (Salama & Said, 2023). Drones and Laser Scanners unlock numerous useful applications in the construction sector that are widely used. Progress monitoring, construction site inspection, safety inspection, material monitoring, supervision and monitoring in hard-to-reach points, topographical capture and scan to BIM, are only some applications (Li & Liu, 2018).

Finally, Big Data Analytics, Mobile/Cloud Computing and Blockchain are technologies that may support Project Managers in great ways. Waste optimization, decision making (Bilal et al., 2016), more efficient project management (Bello et al., 2021), better communication among stakeholders, smart contracts (Li et al., 2019) are some areas of their application. All the aforementioned technologies and ways of working appear to be significant to the construction Industry as it moves boldly towards incorporating sustainability in its core (Stanitsas & Kirytopoulos, 2021). Construction 4.0 is expected to boost this endeavour by the introduction of new ways of managing, developing and maintaining buildings and infrastructure.

3. Research Method

To investigate the implementation, benefits, and challenges of Construction 4.0 technologies in Greece, interviews and focus groups were selected as the research method due to their ability to provide qualitative insights. This approach aligns with the study's aim to map and assess the integration of Construction 4.0 tools in the Greek Construction Sector, facilitating in-depth analysis through dialogue. Criteria for selecting entities focused on companies active in Greece, with an emphasis on larger firms likely using advanced technologies, given the nascent stage of Construction

4.0 globally. The selection of interviewees prioritized project management or IT management professionals, ensuring experienced insights balancing strategic understanding with hands-on experience. This methodology ensures rich, qualitative data crucial for analyzing the sector's digital transformation.

During the research, 8 interviews and 2 focus group conversations were conducted involving 13 senior project managers and project directors, with decades of experience in the Greek Construction Sector. The six companies that those people work for are among the largest construction or project/portfolio management companies in Greece (based in Greece but may also operate generally in Southern Europe as well as Middle East), referred as 6^{th} or 7^{th} grade companies (the maximum grade for construction companies i.e. they are allowed to undertake projects of any size). Large companies have more resources to adopt advance technologies like Construction 4.0 and smaller ones may have lower adoption rate. The interviews were conducted using open ended questions that triggered dialogue and free conversation. The first question explored revolutionary technology in the Greek Construction Sector in the latest 10 years. This way the interviewees exposed their experiences and opinions about the topic. Most of them expanded the conversation and answered the remaining question without even being questioned. They answered about the applications of construction 4.0 technology in Greece, benefits and barriers of adaptation and future trends.

The data were captured by taking notes during the interview (a strict ethical protocol was followed to reassure the privacy and free will participation of the interviewees) and some of them (after permission of the interviewees) were also recorded. Then the gathered “raw” data were analyzed using the Affinity Diagram technique (Blixt & Kirytopoulos, 2017). First of all, the phrases of the interviewees were recorded, categorized and organized. Every phrase that provided new information was captured as a new “image” (see black labels in Fig. 1). Then “images” referring to the same phenomena were grouped (see red labels in Fig. 1) and, at the highest level, that of complete concepts, final affinities (see green labels in Fig. 1) were formed. Fig. 1 depicts one example of the affinities’ formation. The 16 affinities that were identified in total constitute the Affinity Map, which again was eventually formed using affinity and information exchange among them. This map is a scheme which represents a holistic view of the Greek Construction Sector, revealing insights about the current situation and the reasons behind it (to be discussed later in Fig. 2).

4. Results

4.1 The Greek Construction 4.0 landscape

Fig. 1 represents one of the 16 Affinity Diagrams that were formed. This is the diagram D16 and is about Extended Reality. It is shown here in order for the reader to better understand the Affinity Diagram technique and realize how affinities occurred. The other 15 diagrams are not shown here due to space limitations but the highest-level affinities are described hereafter, as well as through the Affinity Map.

Affinity Diagram D1: BIM is a revolutionary tool in the construction sector, necessary and practically beneficial for the constructors of large and complicated projects. When the interviewees were asked which technology had impressed them the most in recent years, the majority of responses highlighted BIM as the tool that has revolutionized the way the Construction Sector operates to date. Practically, it offers facilitation of complex designs, coordination among architectural, structural, electrical/mechanical, and other studies, elimination of the trial-and-error approach and savings in time, cost, and personnel. BIM facilitates the coordination of all parties involved in a project and contributes to optimal management, transmission, and processing of information among Project Managers, workers, and, of course, clients. This aspect is of paramount importance for executives and companies in terms of cost and time savings.

Affinity Diagram D2: BIM is a tool that seems beneficial in high budget (>100M€), large and complicated buildings. It doesn’t seem to have gained much attention in underground projects and road and railway networks projects. BIM primarily offers solutions for large-budget projects, typically in the order of 100 million euros. Examples informed by interviewees include the Piraeus Tower, the Rio-Antirrio Bridge, the Stavros Niarchos Foundation, and various hospitals. Such projects are designed using BIM, and it appears to be advantageous for projects of this budget scale and complexity. For the construction of roads, underground pipelines, and ductworks, BIM is currently of limited interest, as informed by the infrastructure projects specialist interviewee.

Affinity Diagram D3: It is very beneficial for clients to have their project delivered in BIM. Because BIM has several benefits in operations/maintenance phase and eases the conversion to smart building. BIM is highly beneficial for clients (those receiving the project) during the construction phase, as it allows for a live digital visualization of the project's progress in terms of scheduling and cost management, through what is known as 5D-BIM. In the operation/maintenance phase of a building, having all project information in a digital file is invaluable for equipment maintenance, repair scheduling, and fault prediction. Additionally, the integration of BIM with other technologies such as IoT (Internet of Things) and DT (Digital Twins) facilitates the transformation of the building into a smart building.

Fig. 1 *Affinity Diagram D16 – Extended Reality*

Affinity Diagram D4: It seems that the clients and the public sector ask for BIM in their project specifications. This is a crucial factor for the spread of BIM both now and for the future, among the large constructors. Most interviewees emphasized that it is the clients who demand their projects be delivered using BIM. While this tool offers numerous benefits for contractors and designers, they would unlikely deviate from the conventional procedures that have been in place for years on their own. Therefore, clients are the driving force and, as seen by the industry trends, are likely to strongly motivate companies to utilize BIM. Similarly, the public sector acts in the same manner, both by requiring BIM for public projects and by enacting legislation for the implementation of BIM in Greece.

Affinity Diagram D5: Currently, it is difficult for BIM to spread in smaller projects, because it's an expensive tool and requires specialized users, that are hard to find. BIM is not a mere design tool of the AutoCAD variety that anyone can master after a few hours of engagement. In contrast, it constitutes a challenging, complex, and intricate instrument, more of a holistic methodology. Even experienced Project Managers do not necessarily possess the proficiency to operate within it. However, it is imperative that they understand and can interpret it. Consequently, a financial investment by the company is required to train its personnel. An alternative solution is to turn towards a specialized BIM design office, yet this approach remains costly. When one also considers the expense of the software itself, the total investment is significant. Therefore, as we shall see, an equivalent Return on Investment (ROI) is necessary for it to be considered beneficial. Overall, these challenges seem insufficient to hinder BIM progress.

Affinity Diagram D6: In the future, BIM is going to expand even more in large projects, but the spread is doubtful for smaller projects. In the future, it is certain that BIM will further develop and become an integral tool even for companies of smaller scale. However, it is questionable whether BIM will be adopted for smaller projects because, although its cost may decrease due to economies of scale, it might not prove to be cost-effective. For instance, using it for the construction of a simple apartment building could be considered excessive.

Affinity Diagram D7: The Greek market is still immature to embrace advanced technologies. Time and financial investment will be required for digitalization and training of all stakeholders. The digital transformation endeavor of the Greek Construction Sector requires, on one hand, a shift from a regressive mindset towards a drive for modernization, and on the other hand, education and financial investment from all stakeholders to achieve significant progress. However, it is an initiative that necessitates the coordination of all interested parties for its success. For instance, it is not feasible for a company to employ BIM in its designs if the sub-contractor responsible for installing the plumbing or electrical/mechanical systems is unable to interpret it.

Affinity Diagram D8: It is difficult for companies to embrace the advanced technologies of Construction 4.0, because there is internal undereducation and sometimes bad communication between employees and managers. Internal issues within companies pose challenges to their technological advancement. The low level of employee training makes it more difficult for them to adapt to change, consequently becoming an obstacle in adopting advanced tools. Additionally, it is quite challenging for large, cumbersome organizations to implement change and invest in new technology because the management often fails to heed the requests of lower-ranking employees, such as Project Managers, who experience the needs of their teams firsthand.

Affinity Diagram D9: The Construction 4.0 technologies have several qualitative benefits for all stakeholders. However, a more clear and appealing calculation of their return on investment (ROI) will be the crucial factor for the companies to be motivated to adopt them. These technologies undoubtedly offer certain qualitative benefits, such as in Environmental, Social, and Governance (ESG) criteria and Corporate Social Responsibility (CSR), pertaining to the company's societal responsibility and its environmental and sustainable development. Many of their applications contribute to increasing worker safety and reducing emissions. However, the unanswered question remains whether it is worthwhile for companies to invest in these technologies and whether there will be a corresponding return on investment.

Affinity Diagram D10: Mobile/Cloud Computing are tools that are not new in the Greek Construction Sector. The contractors are extremely interested in them, because they contribute significantly in the better information management and sharing, thus in improved project management. Cloud-Based systems and software are deemed exceptionally useful for Project Managers as they facilitate collaboration among all parties involved in a project, ensure smooth management and transmission of information and provide other conveniences. Additionally, their integration with tablets and mobile devices (Mobile Computing) proves to be very beneficial. Improved communication and information flow prevent delays in scheduling, thereby leading to time and cost savings.

Affinity Diagram D11: Robotics is a technology that currently is applied in very specific cases and circumstances in the Greek Construction Sector. However, the companies seem positive to embrace them in the near future. Robotic machines are tools that require very specific conditions to operate due to their high degree of automation. In an industrial setting, everything is defined, whereas, at a construction site, conditions are much more unpredictable and unclear. Nonetheless, there are applications in Greece in specific cases, as the interviewees stated. Floor marking robots, automatic grader/finisher using IFC data from BIM and remote control of machinery in a photovoltaic project are some applications mentioned from the interviewees.

Affinity Diagram D12: Sensors and IoT (Internet of Things) are useful in construction phase, but mostly in operations/maintenance phase. Tests for usage in more applications are being done but there are barriers. During the construction phase, sensors have been used but without internet connectivity. There is a foundation, yet an upgrade is necessary. In the operation/maintenance phase, applications such as monitoring the behavior of bridges and stresses of skyscrapers were noted. Remarkably, access to more advanced applications, such as live monitoring of worker locations on a construction site, concrete curing, or control of electricity consumption through sensors, was explored but not implemented because they were deemed not essential but costly.

Affinity Diagram D13: Digital Twins is a technology in nuanced stages in the Greek Construction Sector, which is only used in the operations/maintenance phase and not in the construction phase. There was no case of use during the construction phase but only for operations/maintenance. An interesting mention was made regarding the expected use of digital twins (alongside IoT sensors & BIM) again in the operation/maintenance phase, once the Piraeus Tower project is completed. The purpose is to simulate and compare the initially calculated consumptions from the as-built BIM with those of the actual building.

Affinity Diagram D14: Drones and Laser Scanners are common technologies in high budget projects having important applications like topographic mapping, project inspection, progress monitoring and other more sophisticated uses. Drones have proven to be a common technology in the Greek construction sector with widespread and significant use, primarily for topographical studies and recordings, as well as for surveillance, supervision, and automated monitoring of project progress, especially in inaccessible areas. A particularly interesting application was noted in the Piraeus Tower, where laser scanning (mounted on a drone) of the top of a high-rise building was conducted to create a three-dimensional model and perform aerodynamic simulations.

Affinity Diagram D15: Additive Construction or 3D-Printing in construction, is a technology that is currently not used at all in Greece. There are some practical issues, that may be resolved, when the price drops and the Return on Investment (ROI) is improved. Additive Construction, commonly known as 3D Printing, in the construction sector, currently has no application in Greece. Most interviewees had no experience with 3D Printing in construction (i.e., with the deposition of concrete). Specifically in Greece, many emphasized that the challenge is greater due to the seismic nature of the region and that the Return on Investment (ROI) is currently very low.

Affinity Diagram D16: Extended Reality technology (AR/VR) is not currently used in the construction phase in the Greek Construction Sector, but mainly for commercial purposes. Although it seems that there are several benefits and there are specialized dealers offering advanced solutions in construction phase, barriers arise. Virtual Reality (VR) is definitively utilized for virtual presentations of projects, either in three-dimensional designs or video format for commercial purposes, to clients, for demonstration or for agreement on specifications and requirements. Some consider it beneficial also during the construction phase for facilitating the understanding of complex constructions, while others believe VR is solely a commercial tool. Nonetheless, two cases of trial use during the construction phase were noted. One case involved training for work at heights with VR simulation. The second case involved the use of a special Augmented Reality (AR) mask for live fault diagnosis of the project by comparing reality with BIM and digitally highlighting defects or omissions.

Other technologies: Off-site construction in Greece is analogous to the concept elsewhere, but instead of specialized contractors, it is dealt with by aluminum manufacturers. Lasers, often mentioned in conjunction with drones, had a broad usage. A notable application was "scan to BIM," which involved scanning a building and digitally representing it in BIM. Big data analysis was conducted to decide from an environmental standpoint whether it would be more beneficial for the Piraeus Tower to be demolished and rebuilt from scratch or renovated. Ultimately, the result indicated that renovating the building would have a smaller environmental footprint.

4.2 Driving forces that shape Construction 4.0 in Greece

The current situation in the Greek Construction Sector is depicted using the Affinity Map (see Fig. 2). This schematic diagram involves all the Affinity Diagram headings (representing the main idea of each of them) and the relation among them. The one-direction arrows show flow of information, the bidirectional arrows show information exchange and the bidirectional arrows with the perpendicular line, show contradicting information. The orange dot represents the suggested reading start point.

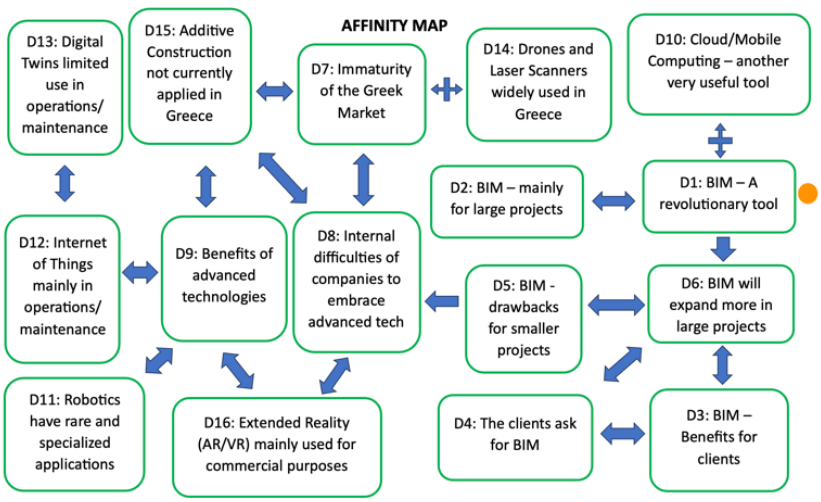

Fig. 2 *Affinity Map for the Greek Construction Sector current situation*

The most revolutionary, useful, and widely adopted technology in the Greek Construction Sector within the framework of Construction 4.0 is BIM, primarily applied in major projects. A contending viewpoint posits that Cloud-Based systems technology was the most groundbreaking, deemed also as significantly vital and widespread. BIM is anticipated to further proliferate among large construction entities, though its extension to smaller projects remains questionable for two primary reasons. Predominantly, an increasing number of clients, including the public sector, are mandating BIM in their project delivery specifications. Secondly, BIM offers substantial benefits for constructors and designers themselves. However, its adoption in smaller projects will not proceed at the same pace due to the necessity for trained personnel and substantial financial investment for acquisition and operation. Regarding other advanced Construction 4.0 technologies, their widespread adoption by companies faces challenges attributed to a tripartite responsibility. This encompasses the companies' internal responsibilities, the immaturity and lack of education within the Greek Construction Sector, and the uncertain Return on Investment (ROI) for these advanced technologies. The only exception to this perspective involves Drones and Laser Scanners, technologies extensively utilized in the Greek Construction Sector. Conversely, 3D printing and Digital Twins affirm this view, with few uses in the sector, followed by Robotics, Extended Reality, and the Internet of Things, which have a minimal presence and are mainly in experimental phases.

At the technological level, the technologies Presence Histogram (Fig. 3) indicates the engagement of the professionals involved in the total of 10 interviews/focus groups conducted, with the Construction 4.0 technologies.

For each of the 12 technologies mentioned, the black bars indicate the number of interviews/focus groups where the technology was confirmed to be used in the Greek Construction Sector, the grey bars indicate the number of interviews/focus groups where the professionals were just aware of applications of the technology and the white bars indicate the number of interviews/focus groups where the professionals were not aware about real-world applications of the technology. Fig. 3 corroborates the Relevance Map, indicating that BIM, Cloud Computing technologies, and Mobile Computing are the most prevalent technologies in the Greek Construction Sector, featured in all 10 interviews and group interviews conducted. Drones and Laser Scanning technologies also enjoy universal usage and are now considered standard tools for Project Managers. Subsequently, Robotics (R/tics), Internet of Things (IoT), and Extended Reality follow in terms of popularity. They exhibit a moderate degree of presence in 4 out of 10 instances, which is deemed satisfactory given that these technologies are considered advanced even in the manufacturing sector.

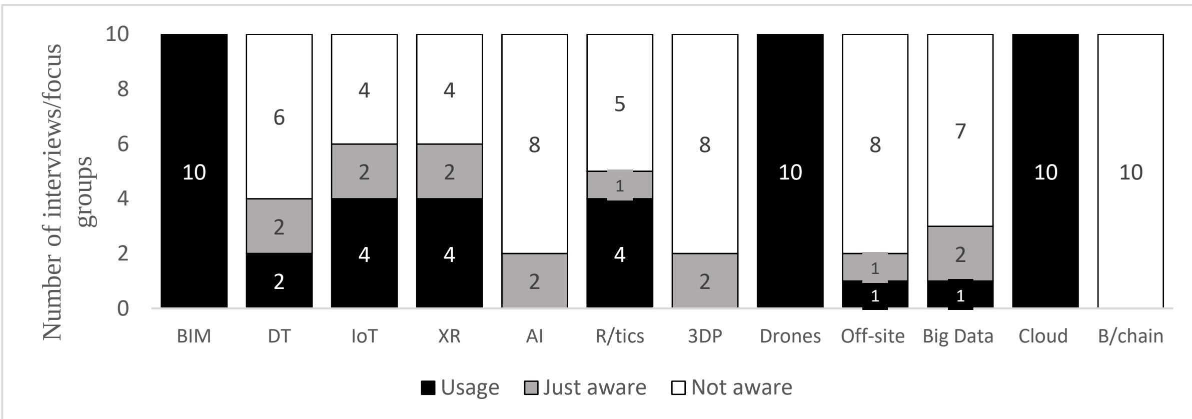

Fig. 3 *Presence of Construction 4.0 technologies in the Greek Construction Sector*

A final group of technologies observed no application cases, with few individuals merely aware of their existence as technologies in the construction sector. These include Artificial Intelligence, 3D Printing, and Blockchain (B/chain). This is understandable as even internationally, these technologies are currently in experimental and early development stages, with limited applications in real construction site conditions.

5. Conclusions and Further Research

The Greek Construction Sector is keeping up with the international circumstances. There is a decent degree of digitization primarily through the adoption of BIM, Cloud technologies, Drones, and Laser Scanners. These technologies seem to have been widely adapted in the Greek Construction Sector. Now, besides this category of technologies, the Greek Construction Sector reveals sporadic use of others. There are applications of Construction 4.0 technologies in Greece, but the truly advanced often remain in experimental stages. There are specialized dealers that offer very advanced solutions, but the mass use isn't here yet.

The conclusions drawn from this paper serve as valuable insights for stakeholders within the technology and construction sectors, indicating a clear path for evaluating and enhancing their technological advancements in comparison to international standards and the rapid evolution observed in major companies within the Greek Construction Sector. This analysis highlights the imperative for companies to reevaluate their stance towards digitalization, suggesting that overcoming traditional mindsets and investing in digital transitions could unlock significant benefits, including efficiency and cost savings. The encouragement towards adopting Construction 4.0 technologies suggests a win-win scenario, fostering economic growth and sustainability within the sector.

Future research should delve into the unexplored or underestimated benefits of these technologies in the construction sector, as identified in international literature, and perform a quantitative analysis of their economic impact. This research would not only help in pinpointing specific technologies and applications ripe for investment but also assist in crafting targeted, actionable plans for companies aiming to advance technologically. Calculating the Return on Investment (ROI) for each technology and application, combined with the clear benefits of these technologies derived from international literature research, could encourage companies to more assertively adopt some of these technologies. Thus, potentially initiating the comprehensive effort required from all stakeholders to fully integrate Construction 4.0 into the Greek Construction Sector. Such efforts are poised to yield economic advantages and drive the Greek Construction Sector towards a more automated, sustainable future, highlighting the broader impact of technological evolution on industry practices and sustainability.

Acknowledgment

Prof. Kirytopoulos wants to acknowledge that he received funding for travel expenses related to this publication from the Athens MBA faculty development fund.

Reference

Ahmed, S. (2019). A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization, Technology and Management in Construction, 11*(1), 1839-1852.

Akanmu, A. A., Anumba, C. J., & Ogunseiju, O. O. (2021). Towards next generation cyber-physical systems and digital twins for construction. *Journal of Information Technology in Construction, 26*, pp. 505-525.

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building Information Modeling (BIM): Now and Beyond. *Australasian Journal of Construction Economics and Building, 12*(4), 15-28.

Bello, S. A., Oyedele, L. O., Akinade, O. O., Bilal, M., Delgado, J. M., & Akanbi, L. A. (2021). Cloud computing in construction industry: Use cases, benefits and challenges. *Automation in Construction, 122*, 103441.

Bilal, M., Oyedele, L. O., Qadir, J., Munir, K., Ajayi, S. O., & Akinade, O. O. (2016). Big Data in the construction industry: A review of present status, opportunities, and future trends. *Advanced Engineering Informatics, 30*(3), 500-521.

Biswas, H. K., Sim, T. Y., & Lau, S. L. (2024). Impact of Building Information Modelling and Advanced Technologies in the AEC Industry: A Contemporary Review and Future Directions. *Journal of Building Engineering, 82*, 108165.

Blixt, C., & Kirytopoulos, K. (2017). Challenges and competencies for project management in the Australian public service. *International Journal of Public Sector Management, 30*(3), 286-300.

Jepson, J., Kirytopoulos, K., & London. (2020). Insights into the application of risk tools and techniques by construction project managers. *International Journal of Costruction Management, 20*(8), 848-866.

Jia, M., Komeilya, A., Wang, Y., & Srinivasana, R. S. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction, 101*, 111-126.

Khurshid, K., Danish, A., Salim, M. U., Bayram, M., Ozbakkaloglu, T., & Mosaberpanah, M. A. (2023). An In-Depth Survey Demystifying the Internet of Things (IoT) in the Construction Industry: Unfolding New Dimensions. *Sustainability, 15*(2), 1275.

Labonnote, N., Rønnquist, A., Manum, B., & Rüther, P. (2016, December). Additive construction: State-of-the-art, challenges and opportunities. *Automation in Construction, 72*(3), 347-366.

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction, 102*, 288-307.

Li, Y., & Liu, C. (2018). Applications of multirotor drone technologies in construction management. *International Journal of Construction Management, 19*(5), 401-412.

Pan, Y., & Zhang, L. (2023). Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Archives of Computational Methods in Engineering, 30*, 1081-1110.

Salama, T., & Said, H. (2023, April). Agility assessment framework for modular and offsite construction. *Construction Innovation, ahead-of-print*(ahead-of-print).

Singh, M., & Kuts, V. (2022). Applications of Digital Twin across Industries: A Review. *Applied Sciences, 12*(11), 5727.

Stanitsas, M., & Kirytopoulos, K. (2021). Investigating the significance of sustainability indicators for promoting sustainable construction project management. *International Journal of Construction Management, 23*(3), 434-448.

Wang, P., Wu, P., Chi, H.-L., & Wang, X. (2018). A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training. *International Journal of Environmental Research and Public Health, 15*(6), 1204.

Zabidin, N. S., Belayutham, S., & Ibrahim, D. C. (2020). A bibliometric and scientometric mapping of industry 4.0 in construction. *Journal of Information Technology in Construction, 25*, pp. 287-307.