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LNCS 14105

Computational Science and Its Applications – ICCSA 2023 Workshops

Athens, Greece, July 3–6, 2023
Proceedings, Part II

Part II

Springer

Lecture Notes in Computer Science 14105

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Editors

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ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Computer Science
ISBN 978-3-031-37107-3 ISBN 978-3-031-37108-0 (eBook)
https://doi.org/10.1007/978-3-031-37108-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

These 9 volumes (LNCS volumes 14104–14112) consist of the peer-reviewed papers from the 2023 International Conference on Computational Science and Its Applications (ICCSA 2023) which took place during July 3–6, 2023. The peer-reviewed papers of the main conference tracks were published in a separate set consisting of two volumes (LNCS 13956–13957).

The conference was finally held in person after the difficult period of the Covid-19 pandemic in the wonderful city of Athens, in the cosy facilities of the National Technical University. Our experience during the pandemic period allowed us to enable virtual participation also this year for those who were unable to attend the event, due to logistical, political and economic problems, by adopting a technological infrastructure based on open source software (jitsi + riot), and a commercial cloud infrastructure.

ICCSA 2023 was another successful event in the International Conference on Computational Science and Its Applications (ICCSA) series, previously held as a hybrid event (with one third of registered authors attending in person) in Malaga, Spain (2022), Cagliari, Italy (hybrid with few participants in person in 2021 and completely online in 2020), whilst earlier editions took place in Saint Petersburg, Russia (2019), Melbourne, Australia (2018), Trieste, Italy (2017), Beijing, China (2016), Banff, Canada (2015), Guimaraes, Portugal (2014), Ho Chi Minh City, Vietnam (2013), Salvador, Brazil (2012), Santander, Spain (2011), Fukuoka, Japan (2010), Suwon, South Korea (2009), Perugia, Italy (2008), Kuala Lumpur, Malaysia (2007), Glasgow, UK (2006), Singapore (2005), Assisi, Italy (2004), Montreal, Canada (2003), and (as ICCS) Amsterdam, The Netherlands (2002) and San Francisco, USA (2001).

Computational Science is the main pillar of most of the present research, industrial and commercial applications, and plays a unique role in exploiting ICT innovative technologies, and the ICCSA series have been providing a venue to researchers and industry practitioners to discuss new ideas, to share complex problems and their solutions, and to shape new trends in Computational Science. As the conference mirrors society from a scientific point of view, this year's undoubtedly dominant theme was the machine learning and artificial intelligence and their applications in the most diverse economic and industrial fields.

The ICCSA 2023 conference is structured in 6 general tracks covering the fields of computational science and its applications: Computational Methods, Algorithms and Scientific Applications – High Performance Computing and Networks – Geometric Modeling, Graphics and Visualization – Advanced and Emerging Applications – Information Systems and Technologies – Urban and Regional Planning. In addition, the conference consisted of 61 workshops, focusing on very topical issues of importance to science, technology and society: from new mathematical approaches for solving complex computational systems, to information and knowledge in the Internet of Things, new statistical and optimization methods, several Artificial Intelligence approaches, sustainability issues, smart cities and related technologies.

In the workshop proceedings we accepted 350 full papers, 29 short papers and 2 PHD Showcase papers. In the main conference proceedings we accepted 67 full papers, 13 short papers and 6 PHD Showcase papers from 283 submissions to the General Tracks of the conference (acceptance rate 30%). We would like to express our appreciation to the workshops chairs and co-chairs for their hard work and dedication.

The success of the ICCSA conference series in general, and of ICCSA 2023 in particular, vitally depends on the support of many people: authors, presenters, participants, keynote speakers, workshop chairs, session chairs, organizing committee members, student volunteers, Program Committee members, Advisory Committee members, International Liaison chairs, reviewers and others in various roles. We take this opportunity to wholehartedly thank them all.

We also wish to thank our publisher, Springer, for their acceptance to publish the proceedings, for sponsoring part of the best papers awards and for their kind assistance and cooperation during the editing process.

We cordially invite you to visit the ICCSA website https://iccsa.org where you can find all the relevant information about this interesting and exciting event.

July 2023

Osvaldo Gervasi
Beniamino Murgante
Chiara Garau

Welcome Message from Organizers

After the 2021 ICCSA in Cagliari, Italy and the 2022 ICCSA in Malaga, Spain, ICCSA continued its successful scientific endeavours in 2023, hosted again in the Mediterranean neighbourhood. This time, ICCSA 2023 moved a bit more to the east of the Mediterranean Region and was held in the metropolitan city of Athens, the capital of Greece and a vibrant urban environment endowed with a prominent cultural heritage that dates back to the ancient years. As a matter of fact, Athens is one of the oldest cities in the world, and the cradle of democracy. The city has a history of over 3,000 years and, according to the myth, it took its name from Athena, the Goddess of Wisdom and daughter of Zeus.

ICCSA 2023 took place in a secure environment, relieved from the immense stress of the COVID-19 pandemic. This gave us the chance to have a safe and vivid, in-person participation which, combined with the very active engagement of the ICCSA 2023 scientific community, set the ground for highly motivating discussions and interactions as to the latest developments of computer science and its applications in the real world for improving quality of life.

The National Technical University of Athens (NTUA), one of the most prestigious Greek academic institutions, had the honour of hosting ICCSA 2023. The Local Organizing Committee really feels the burden and responsibility of such a demanding task; and puts in all the necessary energy in order to meet participants' expectations and establish a friendly, creative and inspiring, scientific and social/cultural environment that allows for new ideas and perspectives to flourish.

Since all ICCSA participants, either informatics-oriented or application-driven, realize the tremendous steps and evolution of computer science during the last few decades and the huge potential these offer to cope with the enormous challenges of humanity in a globalized, 'wired' and highly competitive world, the expectations from ICCSA 2023 were set high in order for a successful matching between computer science progress and communities' aspirations to be attained, i.e., a progress that serves real, place- and people-based needs and can pave the way towards a visionary, smart, sustainable, resilient and inclusive future for both the current and the next generation.

On behalf of the Local Organizing Committee, I would like to sincerely thank all of you who have contributed to ICCSA 2023 and I cordially welcome you to my 'home', NTUA.

On behalf of the Local Organizing Committee.

Anastasia Stratigea

Organization

ICCSA 2023 was organized by the National Technical University of Athens (Greece), the University of the Aegean (Greece), the University of Perugia (Italy), the University of Basilicata (Italy), Monash University (Australia), Kyushu Sangyo University (Japan), the University of Minho (Portugal). The conference was supported by two NTUA Schools, namely the School of Rural, Surveying and Geoinformatics Engineering and the School of Electrical and Computer Engineering.

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Advances in Artificial Intelligence Learning Technologies: Blended Learning, STEM, Computational Thinking and Coding (AAILT 2023)

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Advanced Processes of Mathematics and Computing Models in Complex Computational Systems (ACMC 2023)

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Artificial Intelligence Supported Medical Data Examination (AIM 2023)

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Advanced and Innovative Web Apps (AIWA 2023)

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Assessing Urban Sustainability (ASUS 2023)

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Advances in Web Based Learning (AWBL 2023)

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Bio and Neuro Inspired Computing and Applications (BIONCA 2023)

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Choices and Actions for Human Scale Cities: Decision Support Systems (CAHSC–DSS 2023)

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Computational and Applied Statistics (CAS 2023)

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Cyber Intelligence and Applications (CIA 2023)

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Conversations South-North on Climate Change Adaptation Towards Smarter and More Sustainable Cities (CLAPS 2023)

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Gender Equity/Equality in Transport and Mobility (DELIA 2023)

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International Workshop on Defense Technology and Security (DTS 2023)

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Integrated Methods for the Ecosystem-Services Accounting in Urban Decision Process (Ecourbn 2023)

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Evaluating Inner Areas Potentials (EIAP 2023)

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Sustainable Mobility Last Mile Logistic (ELLIOT 2023)

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Econometrics and Multidimensional Evaluation of Urban Environment (EMEUE 2023)

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Ecosystem Services in Spatial Planning for Resilient Urban and Rural Areas (ESSP 2023)

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Ethical AI Applications for a Human-Centered Cyber Society (EthicAI 2023)

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13th International Workshop on Future Computing System Technologies and Applications (FiSTA 2023)

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Collaborative Planning and Designing for the Future with Geospatial Applications (GeoCollab 2023)

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Geomatics in Agriculture and Forestry: New Advances and Perspectives (GeoForAgr 2023)

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Geographical Analysis, Urban Modeling, Spatial Statistics (Geog-An-Mod 2023)

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Application and Evaluation of a Cross-Fertilization Methodology in the AEC Industry: New Technologies, Digitalization and Robotization

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Abstract. The construction industry (AEC) has been stuck in a state of lagging innovation for too long, especially when certain processes are deepened. Excluding research into innovative and high-performance materials, it is difficult to stimulate and introduce new updates in other sectors.

In this historical context - NextGenEU, Green Deal, Horizon Europe - the AEC is called upon to assimilate the advances that Industry 4.0, digitization and robotization are introducing. This will have to happen quickly and with different types of innovations: technological, in management processes and in the economic structure of companies.

The aim of this paper is to design a methodology to classify useful innovations for an established sector and to determine which ones are more difficult to adopt and implement successfully. This was done by applying the methodology of the so-called "cross-fertilization" of knowledge spheres. This methodology is based on the principle that multidisciplinary interaction of projects and technologies leads to a network of innovative ideas.

The original contribution of this paper is the definition of the characteristics arising from the cross-fertilization process and the qualitative assessment of their applicability in a stated scenario: the worksite of large-scale infrastructure projects, with a particular focus on the management and monitoring of work progress and the construction of tunnels. The analysis of the results highlights four areas of action for implanting innovations in AEC and how this is only possible through a multi-disciplinary and integrated process.

Keywords: Innovation · Industrial Cross-fertilization · Digitalization

1 Introduction

Over the years, within the AEC industry - Architecture, Engineering and Construction - a status quo in the operative approach and method has been maintained. This has highlighted the difficulty in the introduction of new technologies and innovations on a large

O. Gervasi et al. (Eds.): ICCSA 2023 Workshops, LNCS 14105, pp. 676–689, 2023.
https://doi.org/10.1007/978-3-031-37108-0_43

scale [1], often one-off and dedicated (e.g. new materials). The latency in the introduction of new technologies in AEC can be traced back to several inhibiting factors: the small number of economies of scale within a highly fragmented sector [2]; the absence of initiatives and training of companies and employees [3]; and the multidisciplinary nature of each project and the presence of multiple teams generate difficulties in recognizing roles, responsibilities and distribution of benefits [4].

With the advent of the fourth industrial revolution, we are witness of an acceleration in the digitalization and automation of work that will have an enormous impact on the work and career experiences of individuals [5]. In the latest recovery plans and new development strategies on an International scale and promoted by the European Union, a key role is played by Digitalization. The European Green Deal identifies digital transition as one of the two pillars on which to formulate its strategies [6] to be implemented through the plans promoted by the NextGenerationEU fund [7]. Within them, a number of themes of interest are highlighted in this contribution: Research and innovation - to boost economies and competitiveness; Employment support and job creation - to support job creation and transition to new sectors and types of work; Connectivity - fast and accessible digital connectivity; Energy efficiency in buildings - investment in energy renovations and compliance with the highest energy efficiency standards [8]. The latter is conceptually extendable to the entire AEC industry.

The Cluster 4 - Digital, Industry and Space - of Horizon Europe itself emphasizes how investment in research in this sector can support Europe's technological and economic competitiveness. Some specific areas of intervention are also highlighted: a human-centered and ethical development of digital and industrial technologies; digital and emerging technologies for competitiveness and fit for the Green Deal [9]. The whole plan outlines a circle of initiatives, strategies, and guidelines at European level on the digitalization of processes and infrastructures. Indeed, the AEC and related industries are stimulating the adoption of advancements in artificial intelligence and Internet of Things (IoT) ecosystems to increase productivity and economics value [1].

This contribution attempts to answer some questions arising from the difficulty of introducing digital and robotic innovations within the AEC; an industrial cross-fertilization methodology will be developed to investigate the main innovative trends: intelligent robotics; cloud VR/AR and AIoT; Digital Twins; 4D printing and Block-chain [10].

Which industries innovate the most?

Do they prefer digital systems or the introduction of robotic systems in a given context? How can these innovations be introduced in AEC?

In order to address these questions, 125 innovations were identified within 9 target sectors. From their analysis, in relation to their possible applicability in the construction of large infrastructures and the management of complex construction sites, four possible alternatives for their classification come out.

The paper is divided into five parts: the second is useful to provide a context around which to focus the research. The concepts of Building Information Model (BIM) and Digital Twin (DT) will be introduced as well as motivating the issues that inhibit innovation within the AEC.

The third part proposes and explains the original methodology used, which cross-fertilizes critical literature analysis. In the first instance, two of the problems present in an AEC are identified: the maintenance of the Tunnel Boring Machine (TBM) head and the tracking of the progress of huge worksites.

In the remaining parts, the results will be analyzed, and conclusions will be drawn regarding the methodology used. For the development of this methodology and its application, reference is made to the activities carried out by UniWeLab, a Joint Lab of the University of Genoa, which involves volunteer students from different disciplines doing research on real problems, identified by the collaboration between the University and Webuild, a leading Italian multinational in the large infrastructure construction sector.

2 Background

Referring to digital innovation in AEC, the thought goes to the modification of operation sequences and processes, caused using digital technologies [11]. The challenge is to have a process that is able to encompass the various components around the realization of an infrastructure, in which engineering and economics aspects are no longer than only few of the branches. From this assumption, new technologies will improve and change operations and processes, requiring changes in overall security, adaptive business, and sustainability. [12–14]. Therefore, at all stages of the infrastructure life cycle, from preliminary design to execution and maintenance, they are required to adopt digital models that facilitate the project management process [15].

Precisely with a view to a circular economy for AEC, several studies focus on the generation, evaluation and valorization of construction and demolition waste (CDW) [16, 17]; this is mainly due to the fact that the current recycling system for these materials has a high environmental impact and a considerable level of resource waste [18, 19]. Bringing CDWs within a circular vision in the AEC industry, as well as digitization, has encountered socio-economic barriers related to resistance to cultural change and the high cost of making a profit only in the long run [16].

In recent years, much attention arose around technologies such as BIM and DT as tools to be implemented and useful for the life cycle management of infrastructure and buildings [20]. BIM is an important tool for a complete digitalization of the building process; however, this innovation process is mainly developed by the tool providers themselves [21] and the innovation itself can be classified as product or service innovation, or related to operational and management practices, methods and processes [22]. Instead, a Digital Twin is a complete simulation of a real system through which to model its behavior as parameters and operational scenarios change in order to predict how it will respond [23]. Although DTs are still in their infancy, BIM systems are already more solid. However, in the literature many researchers refer to DTs interchangeably with BIM [24]. This underlying confusion may be among the problems that prevent a "smooth" implementation of these tools.

In addition to BIM and DT, artificial intelligence (AI) is increasingly being adopted by organizations, but implementation is often done without carefully consideration of the employees who will work with it. If employees do not understand or work with AI, it is unlikely to bring value to the company [25].

Another topic of relevance is the safety of and on construction sites. Focusing on AEC, conceptual designs for safety management based on the use of AI directly on the construction site were first proposed [26]; the influence of site layouts on construction workers' perceptions of robots and how their layouts affect the smooth running of site activities was also studied [27, 28].

Furthermore, among the issues that inhibit investment in digitalization and automation in AEC, it has been noted how they can contribute to wages and careers' inequality in low and medium-skilled jobs [29, 30]. However, it has been shown that in the sectors implementing robotics, inequality in the employment/population ratio is minimal [31], especially when compared to the impact of other capital and technologies [28]. In fact, project management in the construction industry presents unique challenges, which have a clear impact on project success. This is due to the fact that each project has unique characteristics such as: location, number of personnel, specific equipment, integrated logistics, cost variations and business capabilities. These are all factors that influence the design and make up the complex space of maneuvering in management [32].

Thus, referring to the major problems in the construction sector, the following items mainly emerge: labour shortages; site safety; site management and worksite organization; optimal use and processing of materials; personnel training and updating. These are all industrial systems' issues that are responsible for the delay the introduction of new technologies.

3 Methodology

As the previous section has shown, there is neither much past expertise nor novel motivation to introduce new technologies within the AEC and this is mainly due to the specific boundary conditions that differ from project to project.

For this reason, the UniWeLab research group identified the need to introduce a new methodology that could help the development of new solutions. This is the case of a context, such as that of Genoa. The City sees numerous works being carried out, involving excavations in complicated territories and the management of construction sites that are large in terms of the number of activities, companies and workers (e.g. Terzo Valico - Cociv, Sub-port Tunnel, New Outer Dam, New Waterfront).

The methodology proposed and used by the consists of three steps (see Fig. 1): a targeted literature analysis; the identification of the main issues under study; the application of industrial cross-fertilization to identify the industries that innovate the most and their affinity with AEC. This approach investigates if and how technological and cultural cross-fertilization from other industries is possible for AEC (see Fig. 1).

All outputs contribute to the final classification of the four areas of intervention, which will be commented on in the fourth section of the paper.

3.1 Literature Analysis

The literature review is conceived as a preliminary step in the start-up of the methodology, the purpose of which is to provide basic training on the subject of investigation and its issues: in this case, it is about digitalization within the AEC industry.

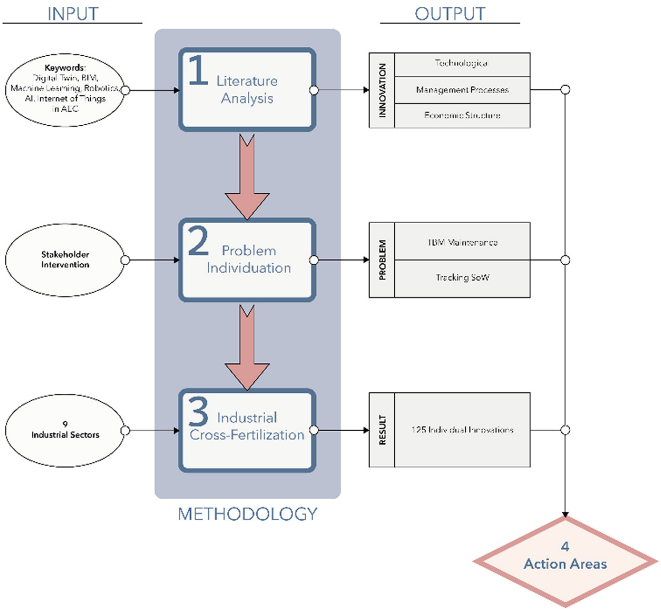

Fig. 1. Example diagram of the proposed methodology.

The first part of the literature analysis consists of identifying articles that make up the starting framework. This was done by asking the students in the research lab to cross-reference some keywords on Google Scholar and Scopus: Digital Twin, BIM or Building Information Model, Machine Learning, Robotics, Artificial Intelligence or AI, Internet of Things or IoT. Each of these had to be accompanied by the terms: AEC or AEC Industry or Construction Sector. Furthermore, some minimum criteria were used to refine the search: published and open access articles, in English. This first part composes the necessary input for the start of phase 1 of the methodology (as in Fig. 1).

The second part of the literature analysis consists of reading and critically reporting on the selected paper. This is done by identifying some of the main components included in each paper: thesis developed by authors, the solution they identified, analysis of the bibliography they used. Finally, the students were asked to summarize the main topic of the paper they analyzed through a guided critical analysis.

The last part is, therefore, the evaluation of results or outputs. Three types of innovation emerge from the literature review: (I) technological innovations; (II) innovations in management processes; (III) innovation in the economic structure of companies.

Technological innovations (I) include robots working autonomously [33] and alongside workers [34]; machine learning applicated to real time video capturing infrastructures progress [35, 36] or machines for laser scanning in boundary conditions [37, 38].

In management process innovations (II) there are: software for modelling the entire life-cycle of the worksite [39, 40] such as BIM [15, 22] or digital twin [41]; Decision Support System technologies [42–44]; VR and AR tools to support and simulate design [45] or IoT and OT ecosystems - operational technologies [46]; collaborative BIM Decision Framework [47]; a multi-objective Genetic Algorithm "GA" [48]. When talking about GA in AEC, reference is made to models that aim to provide horizontal and vertical support in the organization of mega-projects. This is done through a digital system programmed to verify operations and capable of reconfiguring itself according to changing boundary conditions in order to minimize project duration and cost, optimize resource and maximize quality [49].

Innovation in economic structure of companies (III) are: digital infrastructure for effective and sustainable circular economies [49, 50]; AI integration model based on socio-technical systems theory (STS) [25], managerial business strategies of investing in innovation trends [51].

Concluding the analysis, it is the advent of Industry 4.0 itself that requires companies to reorganize themselves structurally; furthermore, another innovative aspect that emerges is the conscious use of mobile and social devices, in conjunction with specialized professionals able to facilitate the transition, by incurring minimal costs for the distribution of information and knowledge [52].

3.2 Problem Individuation

In identifying the main issues to be studied, certain notions from the previous phase were considered, but added practical and critical reflections emerged from the dialogue with the company.

The inputs from phase 1 of this methodology, it emerges that there is a little appeal in the introduction of new digital and robotic technologies in the AEC, although there is a demand and a need for them. In addition, among the major challenges faced during the tasks that make up each job order, problems emerged related to the identification of critical elements and full-time site management. In addition to these, an issue of highlighted importance by the Webuild managers of the workshop is the issue of operator safety during the most critical tasks.

From the first stated assumption, the issue of monitoring and controlling site activities emerged: tracking of statement of work (SoW). This operation is still poorly digitalized and too dependent on human judgement; SoW Tracking on the construction site is traditionally a non automated activity requiring visual inspection and dependent on human judgement and, therefore, error [35]. This activity therefore can be a primary test bed for the implementation of new technologies or digital ecosystems.

Among the most complex tasks affecting worker safety and health are those inherent in excavation operations. TBMs are widely used in hard rock tunnel excavation due to their optimal performance; however, during tunnel excavation, the rotary head is element that suffers most from wear and therefore subject to the most frequent maintenance operations [53, 54]. These critical operations occur in critical situations for the operator who, consequently, is put at risk.

Thus, in the next steps of the proposed methodology, the possibilities of introducing digital innovations in these two processes involving AEC through a process of Industrial Cross-Fertilization will be analyzed.

3.3 Cross-Fertilization Application

The last part of the proposed methodology uses an industrial cross-fertilization process to understand in which industries, outside the AEC, the major innovations occur and whether they are importable in the construction sector. Building on cross-fertilization concept, that originates in the natural sciences and accelerates the natural evolutionary process [55], various disciplines-marketing, education sciences, management-have inherited this methodology by readjusting it to their needs [56].

Thus, trying to give a definition of Cross-Fertilization as applied to the field of research and development in industry, it can be said that Cross-Fertilization is done when the combination of interdisciplinary technologies and knowledge generates new broader technological opportunities in terms of Product, Performance and Functionality [57–61]. Therefore, the purpose of interdisciplinary cross-fertilization is to avoid inventing something new that already exists; to fill gaps in a field by synthesizing knowledge dispersed across several disciplines towards a single result [62].

For this phase of the methodology, nine industrial sectors were identified in which to research new digital, robotic technologies introduced in recent times: Aeronautics and Aerospace; Agribusiness; Chemistry and Materials; Electronics and Information; Energetics; Military; Mining-Oilfield; Port; Safety and Health.

The search for innovations in other industries was carried out by the students in the UniWeLab laboratory. For each sector, the search was carried out using different methods: web search, scientific articles, company reports and newsletters, trade journals… The output of this third stage of the methodology is a list of innovations to be evaluated. Each element of this list was classified according to its sector of origin and then validated as specified in Sect. 4; the ultimate goal is to determine in which sectors there are more innovations and which of them can be introduced in the AEC and in which areas.

4 Results' Analysis

Through this method, 125 technological innovations in 9 different industrial sectors were identified. Subsequently, a skimming process was introduced to identify unsuitable innovations, which reduced the list to 111; among the reasons why some were excluded were because they were too generic in relation to the contribution they could make, e.g. digital twin or robotics; or because their applicability was too far removed from the relevant sector, e.g. Synthetic Meat.

Table 1 summarizes the results of the list by breaking down the innovations by industry sector of origin at two different points in time: before and after the validation process (see Table 1). The largest digital and robotic innovations identified come from the broad sectors such as Aeronautics and Aerospace and Port (26 and 22 innovations). These are two areas where the demand for innovation is broad and urgent for the proper handling of complex tasks and activities and where precise execution is required. Also relevant is the interest in digital innovation for the Safety and Health sector, underlining how the topic of safety, which has emerged among the crucial issues for AEC, is among the most proactive.

Looking at those sectors that retained the same number of innovations after the skimming process, Mining-Oilfield and Electronics and Information stand out. This could also be due to the affinity of the two sectors with the two issues that emerged in phase 2: TBM maintenance and SoW tracking: two works that, respectively, refer to the processes of excavation and remote verification of activities and their quantification. In the Agribusiness Sector the introduction of AI and robots that facilitate the harvesting process face some challenges attributable to SoW tracking and processing verification. Computer vision technologies are being investigated to identify fruits and vegetables in plantations and locate their position through image retrieval for algorithm operation [63, 64]; another issue concerns the study of manipulators, which must be robust enough to be able to rip the fruit from its seat, but sensitive enough to avoid compromising its integrity [64, 65].

Finally, the Chemistry and Materials sector is the industry area that has the greatest grip within the AEC, as a large part of today's construction activities include retrofitting: an activity where materials that combine high performance and cost-effectiveness are among the most popular.

Table 1. Innovations by industry sector of origin, before and after the validation process.

Industrial Sector	First List		After Validation	
	n.	%	n.	%
Aeronautics and Aerospace	26	23,4	22	19,8
Agribusiness	10	9,0	9	8,1
Chemistry and Materials	8	7,2	7	6,3
Electronics and Information	9	8,1	9	8,1
Energetics	16	14,4	15	13,5
Military	11	9,9	11	9,9
Mining-Oilfield	5	4,5	5	4,5
Port	22	19,8	18	16,2
Safety and Health	18	16,2	15	13,5
	125		111	

The last step in the analysis of the results was to verify the applicability of the innovations within the AEC. This process investigates how to classify (in a descending scale) each innovation within a reference context of the construction industry. As Table 2 shows, it was possible to identify 4 action areas which can introduce a digital and robotic innovation process: Accessory Innovation, System Innovation, Construction Site Innovation and On Operator Innovation.

4.1 Accessory Innovation

Innovations included in the Accessory Innovations are all those new technologies that do not have a possible direct application with respect to the given tasks. However, they can support of other innovations; they have collaborative value e.g. new materials or Hydrogen combustion cell. Their application is to be considered ancillary to other technologies, in order to achieve a higher level of autonomy, safety, sustainability and innovation.

Table 2. Table identifies the 4 action areas in relation to the number of innovations identified.

Classification	n
Accessory Innovation	28
System Innovation	32
Construction Site Innovation	10
On Operator Innovation	41

4.2 System Innovation

System Innovations fall mainly into process innovations, in which the pivotal goal being increased efficiency, reduced costs and time within a production process. It can be seen that, among the sectors investing the most in these technologies, there are the Port, Aerospace and Information industries e.g. Simulators or IoT ecosystem. System innovations make possible to intervene upstream of the worksite, going preventive and generating a safer and more manageable sensor and monitoring system, or platforms that can independently monitor the progress of construction projects and build a systematic strategy for collecting standardized data [66].

4.3 Construction Site Innovation

Construction Site Innovations possess a characterization such that they can act directly within the shipyard system, with possibly minor or major modifications to it. In this case we see a strong inclusion of robots within the sectors taken as examples: agribusiness, military, port and health e.g. Industrial Robots like [67]. These robots can act in three modes: Local Control; Remote Control; and full Autonomous [68]. Each level through which a robot acts indicates a different type of human-robot interface, this, means that depending on the processing at the site it is necessary to plan which robot technology is best suited. Furthermore, the results suggest that separate human-robot sites increase the perceived safety of workers in robotic tasks [10].

4.4 On Operator Innovation

On Operator Innovation means investing directly in technologies that enhance individual human potential. A worker in the construction industry performs wearisome work both physically and at stress levels, so this area includes technologies that safeguard and monitor the health of the operator e.g. mechanical prostheses. The main goal of this kind of innovation is to minimize the risk for operator - before-during-after work - directly protecting human bodies. Finally, there are innovations that utilize the direct presence of the operator on site to verify operations e.g. smart lens for constant monitoring of accessibility.

5 Discussion and Conclusion

Concluding remarks firstly concern to the analysis of the limitations of this research, mainly arising from the context of application. Referring to existent literature, it is possible to point out that, as far as the subsequent stages of the methodology are concerned, the results obtained are sufficient for the identification of the issues around which the specific case study was developed. However, for a future refinement of this methodology, an updating of the analysis through an established methodology, for instance such as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), can be proposed. This procedure is followed for an objective evaluation of the literature, assuming that a bibliography emerging from key word searches in Scopus can be integrated for a greater accuracy of the result.

The application of this kind of methodology requires a rapid development of digitalization and cannot be done alone. Therefore, once the change due to the Industrial Revolution 4.0 is taken into account by the AEC companies, they will have to adapt to the transformation, caring not to settle for one-off solutions aimed at changing a single process, but evolving into an ecosystem architecture for which a bold, conscious and long-term vision is required [46].

Primarily, it important to highlight that AI changed job structures; for example, the use of robots in pharmacy industry reshaped the employment relations between different occupational groups and created new types of professional figures in new jobs [69]. Is this precisely the definition of new tasks that provides the incipit for the digital development of AEC? Relative to the use of AI are increasing figures such as trainers, explainers, and sustainers [70] who are responsible for the proper functioning of AI. In addition, new figures also call for new government policies to encourage and help the reducing the negative impacts of AI on future jobs [71].

This process cannot be steered by sanctions and penalization, because it is now obsolete and ineffective [22]; it is necessary to establish a collaborative and strategic process of knowledge and technology sharing among different sectors to achieve a higher level of innovation. In order to accelerate this change in a static sector like the EAC, disciplinary interaction under the intuition of individual actors is not enough; policies and initiatives from above are needed. With this in mind, the positions adopted at the European level with the aforementioned NextGenerationUE, Green Deal and Horizon Europe projects are aimed at facilitating digitisation in all sectors. Of course, it is necessary to point out that the import process, which is not present within this paper, will have to take place depending on the characteristics of the target sector, and each technology, where it is possible, will undergo more or less significant modifications. In fact, as is evident from the analysis of the results and the four fields of action identified within the AEC, it is not always the case that a new technology has the characteristics for a right implementation in a new sector, but it is the target sector itself that needs to undertake an evolution and an updating. Perhaps for a better implementation of digital within the AEC's worksites, could it be firstly necessary to rethink their configuration?

In conclusion, it emerges that digitalization is expected to create new opportunities and solve old problems, and this can also happen through an integrative process between separate disciplines, knowledge and sectors. Indeed, the cross-fertilization of knowledge and technologies networking is an advantageous mode of operation for innovation in any sector [59, 63].

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