Artificial Intelligence in the Construction Industry: Adoption, Benefits and Risks

Marzia Bolpagni, marzia.bolpagni@macegroup.com
Mace, London, UK

Ivana Bartoletti, ivana@ivanabartoletti.co.uk
Women Leading in AI Network, UK

Angelo Luigi Camillo Ciribini angelo.ciribini@unibs.it
University of Brescia, Italy

Abstract
Recently, Artificial Intelligence (AI) applications powered by increased computational power and large availability of data are increasingly adopted. As all technological products, AI artefacts are not neutral thus can lead discriminatory outcomes. Currently, the literature of information technology in construction is mainly focused on AI applications, related benefits and trends. However, there is a gap in analysing the associated risks. The paper is an exploratory work on ethics in AI in construction and it presents literature review and survey results on adoption, benefits and risks. Results shows that the application of AI in the most advanced construction practices is still limited and most applications cover process automation and process optimization during design. The benefits identified are mainly aligned with literature review. The main risks deal with privacy violation, equality, cybersecurity and ethical aspects. Results help to better understand the needs of the construction community in terms of AI.

Keywords: Artificial Intelligence, Constriction, Adoption, Risks, Benefits

1 Introduction

The construction sector (also named Architecture, Engineering Construction and Operations AECO) is strategic for acquiring and monitoring data as it deals with assets where humans spend most of their time (e.g. to live, work, travel and play) (ISO 2018; Poleg 2019). Therefore, such built assets can be used to monitor the users' behaviors and to understand how humans interacts with each other and operate the space (Poleg 2019). The main value of the built assets is moving from traditional "physical" aspects into "cyber-physical" ones as spaces are valued for what humans can feel and do by using them as it has been echoed by "Space as a Service" or "Space as an Experience" (or "as an Emotion") (Poleg 2019). In addition, the construction sector plays a key role as it deals with sensitive buildings and infrastructures (e.g. defense, law enforcement, or diplomatic buildings; commercial sites involved in storage of valuable materials; landmarks or sites to be used to host events of security significance) (ISO 2018). Having access to the digital replica (digital twin or digital mirror) of a building/infrastructure can provide significant advantages to any malicious users who can easily know where sensitive assets are and how to access and/or disrupt them even remotely (ISO 2018). Moreover, malicious users can understand how the users' experiences and emotions might be surveyed and controlled according to the surveillance-based paradigm (Poleg 2019).

On the past decades, the construction sector has increased the adoption of digital processes and technologies such as Building Information Modelling (BIM) and Internet of things (IoT) (Rafael Sacks, Chuck Eastman, Ghang Lee 2018). More recently, there is an increase in the use of Artificial Intelligence applications due to the availability of both computational power and data (Darko et al. 2020; Pan and Zhang 2021). There are different definitions of AI; in this paper AI is associated to the Artificial Intelligent system defined as software that is developed with one or more of the following techniques and approaches: (a) Machine learning approaches, including supervised, unsupervised and reinforcement learning, using a wide variety of methods including deep learning; (b) Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems; (c) Statistical approaches, Bayesian estimation, search and optimization methods (European Commission 2021a). AI can for a given set of human-defined objectives, generate outputs such as content, predictions, recommendations, or decisions influencing the environments they interact with (European Commission 2021b). By improving prediction, optimising operations and resource allocation, and personalising service delivery, the use of artificial intelligence can support socially and environmentally beneficial outcomes and provide key competitive advantages to companies (European Commission 2021b).

AI artefacts are not neutral as they are created by humans who defines parameters, select datasets, features and adapt to possible uses (Balabanian 2006; Bartoletti 2020; Trine Antonsen 2019). While this is the case for most technological tools, the intrinsic affordances of AI systems mean that human biases embedded in AI artefacts can lead to allocational and representational harms and, ultimately, scale up and automate inequality (Balabanian 2006; Bartoletti 2020; Trine Antonsen 2019).

The potential for AI to carry new risks or negative consequences for individuals or the society (European Commission 2021b) has led to a proliferation of initiatives worldwide which culminated with the publication of the EU AI Act proposal through which the EU Commissions wishes to govern high risk AI followed by a warm response from the US administration indicating the pursuing of fair and trustworthy AI.

Outside construction there have been applications which use breach basic principles of privacy and ethics scaling up inequalities (Bartoletti 2020). Examples include machine-learning powered behavioural targeting which has been connected to online manipulation, including in elections (Cambridge Analytica); facial recognition systems in the spotlight for failing to recognized people of colour; automated decision making systems leading to the perpetuation of inequality in education (UK A level exams, 2020) as well as in welfare states decisions ranging from housing to justice (Bartoletti 2020). The Dutch court case around the fraud algorithm SyRI that, among other pitfalls, had been primarily used in low-income neighborhoods thus wrapping surveillance around the most vulnerable; and the Apple and Goldman Sachs credit card which seemed to offer smaller lines of credit to women than to men: these are only some of the examples showcasing the risk of unfairness in AI systems (Bartoletti 2020).

Currently, the literature of information technology (IT) in construction is mainly focused on studying AI applications, related potentials, benefits, and trends (Darko et al. 2020; Pan and Zhang 2021; Sacks, Girolami, and Brilakis 2020). However, there is a gap in analyzing the risks perceived by the construction experts. Those aspects are essential for a sustainable application of IT in the construction sector. Without a clear and holistic understanding on the risks of AI, it is not possible to act to create common policies and solutions and protect users and communities. In addition, the literature mainly includes applications of AI in construction for research purposes, but it is not clear which is the current adoption in industry.

For this reason, the paper is to be considered as an exploratory work on ethics in AI in construction. The work aims to better understand the needs of the construction community in terms of AI by increasing awareness among academics and professionals on the implementation of AI in the construction sector and the related implications. In this way, it would be possible to prevent incidents and work towards the solution of potential challenges.

2 Literature review on the application of AI in Construction

Deep learning and machine learning (ML) are usually conceived as subsets of the wider domain defined as Artificial Intelligence (European Commission 2021b). Literature review concerning the adoption of AI within the construction sector, over the various stages (design, construction, operations, maintenance, etc.), highlighted how it could strengthen the industry's performances in front of different issues (e.g. creativity, productivity, health and safety, etc.) (Darko et al. 2020;

Pan and Zhang 2021; Sacks et al. 2020). Moreover, the notion of AI has recently been tied to that one concerning the Internet of Things and Digital Twins (Darko et al. 2020; Pan and Zhang 2021; Sacks et al. 2020). The range of applications lies within a broad spectrum: from the reality capture (Scan-To-BIM) process to the recognition of the reinfroced concrete's failures (Darko et al. 2020; Muñoz-La Rivera, et al. 2021; Pan and Zhang 2021; Sawhney et al. 2020). Other applications deal with generative design, process track, autonomous vehicles and robots, process optimization, process management and knowledge capture (Darko et al. 2020; Pan and Zhang 2021; Sacks et al 2020). Nevertheless, apart from the technical solutions regarding buildings and infrastructures, Natural Language Processing started to be tested to support code checking and the semi-automated scheduling applications (Zhou and El-Gohary 2021). In addition, cognitive and semi-autonomous buildings can be supported and enabled by AI (Poleg 2019).

Most of the examples of AI in construction still deal with R&D projects and the literature lacks case studies on the application of AI in industry where benefits have been measured and risks have been discussed. In addition, currently there is not any guidance in how to manage high-risks AI systems (European Commission 2021a) that are related to construction sector.

3 Methods

This section illustrates the research questions and the research method adopted to collect and analyse data.

3.1 Research questions

The research questions covered in this paper are:

- Which is the current level of adoption of AI in the most advanced construction practices?
- Which are the main perceived benefits in using AI in advanced construction practices?
- Which are the main perceived risks in using AI in advanced construction practices?

3.2 Research Methods

To answer the research questions presented above, a research method based on literature review and quantitative and qualitative analysis of primary data has been adopted.

Firstly, literature review has been performed on the use of AI in construction and other industries. The material has been collected from journal papers indexed in Scopus as primary source. In addition, books, standards, and industry reports published by recognized experts and organizations have been analyzed. The keywords used to find online material included: "Artificial Intelligence", "Machine Learning", "Construction", "Built Environment", "Equality", "Privacy", "Ethics", and "Cybersecurity".

Secondly, an online survey has been designed on the results of the literature review. It included a first section on generic information of the attendees and their organizations. The following section included open and close questions on the current use of AI in the industry and in their organizations asking to provide names of applications. It was also asked to share their opinion on benefits and risks in using AI in the construction sector. Attendees were also asked to provide their optional availability for a following up interview. However, results of the interview are omitted in this paper. The survey was voluntary, and the purpose of the research was presented as well as data protection rules. Data was collected anonymously between January and February 2021. Quantitative data was analyzed by using PowerBi and qualitative data was analyzed using Nvivo.

4 Findings from the online survey on the adoption of AI in construction

This section shows the findings of the online survey provided by 105 professionals from the most digitally advanced construction sector practices.

4.1 Collected data

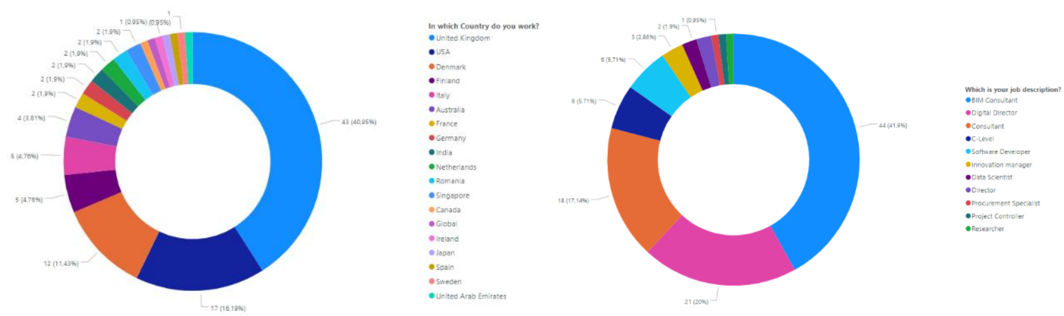
The survey has been shared with experts working in advanced construction organizations that already use other technologies and methodologies including BIM, computational design, extended reality, drones, laser scanning and cloud computing. The organizations have been selected based on national ranking published by professional organizations (e.g. Royal Institute of British Architects in the UK or American Institute of Architects in the USA) as well as national digitalization shortlists in recognized industry awards events (e.g. Construction Magazine) in the past three years in the USA, UK, Finland, Norway, Denmark, Sweden, France, Germany, UAE, Italy, India, and Australia. Most of the selected organizations operate at global scale and therefore some of the participants are based in different countries from the ones mentioned above. The experts of the selected organizations were contacted on LinkedIn based on their job title. Selected job titles included C-level positions as well as data scientist, software developers, BIM Consultants and Innovation managers. The survey was sent to 190 professionals and 105 answers were received (55,26%). The professionals received an invitation where they were informed on the scope of the research and data protection rules. In addition, they received a link to complete the online survey.

4.2 Analysis of collected data

4.2.1 General Information on the participants of the survey

This section illustrates general information regarding the participants and their organizations. It is presented participants' country, job title, years of experience as well as the type of organization they work for and the relative size.

Most of the participants of the survey were from the United Kingdom (41%), followed by USA (16%), Denmark (11%), Finland (5%) and Italy (5%). Less answers were provided by professionals in Australia, France, Germany, India, Netherlands, Romania and Singapore (each representing 2%). Single answers were also provided by experts based in Canada, Ireland, Japan, Spain, Sweden and United Arab Emirates. One expert also did not provide a specific location but selected the option "other" indicating "global" (Figure 1A).



A) B)

Figure 1. Country of participants to the survey and Job description of participants to the survey

The participants were mainly BIM consultants (42%), followed by Digital directors (20%), generic consultants including architects and engineers (17%), C-level members (such as Chief Technical Officers and Chief Executive Officers) (6%), software developers (6%) and innovation managers (3%) and data scientists (2%). The other participants (4%) included individual answers from experts working in organizations as director, a procurement specialist, a project controller and researcher (Figure 1B).

Most participants had 11-20 years (36%) of experience in the industry, followed by people with 6-10 years (35%), 21-30 years (12%), 1-5 years (9%) and 31-40 years (8%).

The participants mainly work for consultancy companies (52%), followed by Construction companies (24%), software developers (7%) and multidisciplinary practices (7%). There were also client representatives (5%), experts working for research and development organizations (3%) and few developers (2%).

The dataset represents people mainly working for large organizations with more than 5000 employees (34%), followed by organizations with 101-500 employees (17%), 1001-3000 (15%), 1-10 (9%), 3000-5000 (9%), 501-1000 (9%), 11-30 (5%) and few from companies with 31-50 (1%) or 51-100 (1%).

4.2.2 Use of AI in Construction

This section shows which are the main areas where AI is used in the construction sector, where it is used in participant's organizations and which are the most promising areas of application. In addition, the construction phases where AI is mainly are shown, both in general and in participant's organizations.

Participants were asked to select all the aspects currently covered by AI applications in construction. The results shows that the main areas deal with process optimization (63%) and process automation (61%). Other areas are process tracking (50%), health and safety (46%), knowledge capture (46%), process management (43%), risk management (40%), cost management (40%), quality management (38%) and sustainability (32%). In addition, some participants selected the "other" option by adding additional aspects related to the "design" (3%) and "constructability" (1%). Finally, 11% stated that there are not any applications of AI in construction now and 6% was not aware of this topic at all.

The participants were also asked to express where AI is currently used in their organizations. Most of them answered that AI is currently used for process automation (44%), followed by process optimization (36%). Other aspects included process management (22%), knowledge capture (21%), sustainability (18%), process tracking (18%), quality management (16%), risk management (11%), cost management (10%) and health and safety (8%). In addition, some participants selected the "other" option by adding additional aspects related to the "design and analysis" (5%) for example identification of cracks from images, façade inspections and reporting, context capture and parametric design using applications such as Dynamo BIM. Many participants stated that AI is not use at all in their organizations (30%) and 6% was not aware of this topic at all.

In addition, participants were asked which are the most promising aspects in using AI for their organizations. Most of them answered that process automation (51%) and process optimization (48%) are the most promising, followed by process tracking (21%), health and safety (23%), knowledge capture (32%), process management (34%), risk management (18%), cost management (3%), quality management (40%) and sustainability (29%). In addition, some participants selected the "other" option by adding additional aspects related to the "design and engineering" including MEP design and extraction of quantities and asset management (3%). Another participant mentioned that AI is considered promising for "e-discovery" and "sensing". Finally, 8% stated that their organizations do not consider AI promising in any areas and 4% was not aware of this topic at all. Figure 2 shows the comparison between the perception of industry adoption, the actual implementation in organizations and the aspects that are considered promising in the future.

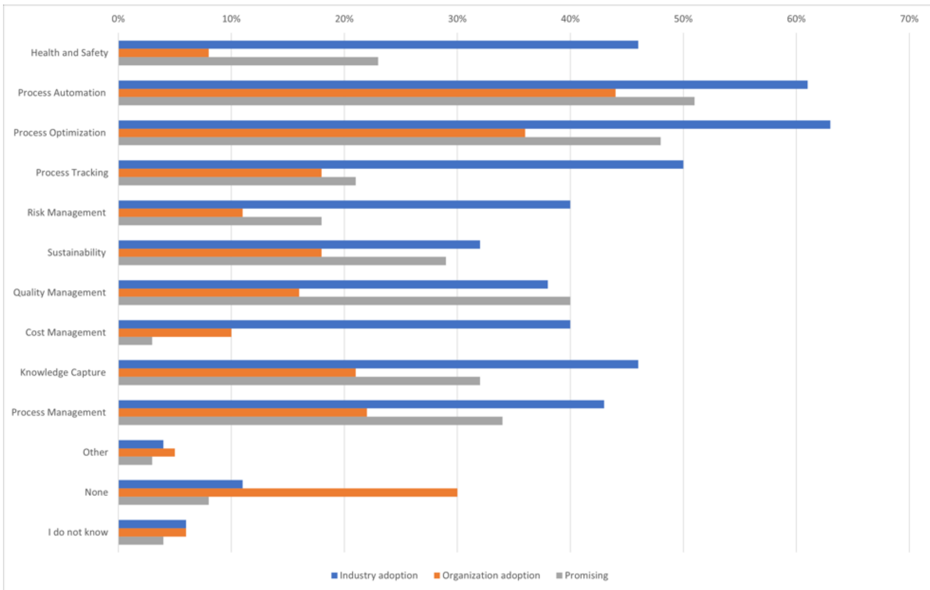


Figure 2 Comparison of aspects related to the use of AI in the construction sector vs used in participant's organizations vs promising areas

Additionally, participants stated that the level of implementation of AI in different construction phases using a scale between none, low, medium, high, very high and I do not know (Figure 3). In the strategic definition, brief, procurement and decommissioning most of the participant mentioned that there is not implementation or low implementation. In the concept and technical design most of the participants stated that there is low-medium implementation. In the manufacturing phase there is almost equal distribution between no implementation, low, medium, and high. In the construction and operation and maintenance most of participants mentioned that the implementation of AI is mainly low.

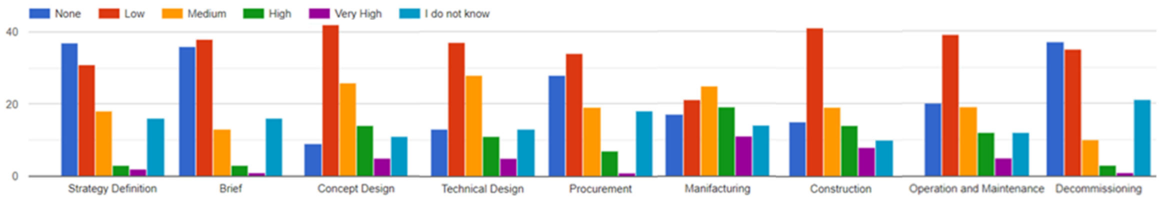


Figure 3. Use of AI in different construction phases

Participants were also asked to provide the name of AI applications used in the industry. The most popular applications mentioned are ALICE Technologies, Smartvid.io, Construction IQ, NPLAN, Spacemaker, Testfit and python. Participants also stated that they develop own products.

In addition, the participants stated the level of implementation of AI in their organizations in different construction phases using a scale between none, low, medium, high, very high and I do not know (Figure 4). In all phases most participants stated that there is not any use of AI applications in any phases. Just few participants confirmed that there is low/medium implementation in the different construction phases. High and very high implementations were confirmed in very few cases.

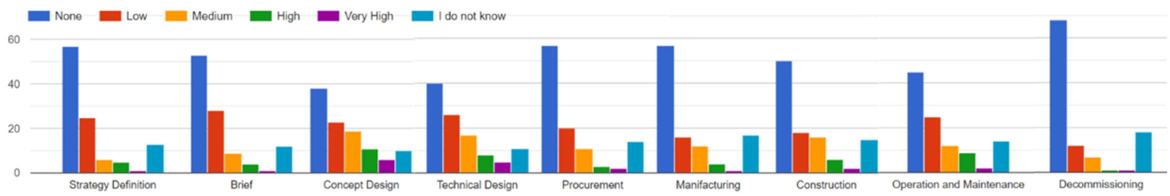


Figure 4. Use of AI in participant's organizations

Finally, participants were also asked to provide the name of AI applications used in their organizations. Just participants who are using AI applications answered this question. Most of the participants develop their own applications, other use ALICE Technologies, n-Plan, Testfit.io, TensorFlow. Python is mentioned as AI application, even if it is mainly a programming language.

4.2.3 Benefits in using AI in Construction

This section illustrates the main benefits in using AI in construction. The participants were asked to evaluate different benefits there were previously identified in the literature review (Darko et al. 2020; Pan and Zhang 2021; Sacks, Girolami, and Brilakis 2020): reduce human error, help in repetitive jobs, help in dangerous job, faster decisions, more accurate decisions, predictive analysis, support h24/7, prevent costs overruns, increase design options, monitor construction progression, improve health and safety on site and improve scheduled maintenance. For each benefit, participants were asked to use a scale between none, low, medium, high, very high and I do not know. Figure 5 shows the results of the survey. High/very high benefits have been identified for helping in repetitive jobs, more accurate decisions, predict analysis, reduce human errors, present costs overruns, increase design options and improve scheduled maintenance. High benefits were also identified in making faster decisions. Less people identified medium/high/very high the monitor of construction progress, taking more accurate decisions and improvement of health and safety on site. Support h24/7 received a balanced number of answers from low to very high. A very limited number of people did not identify any benefits and just few did not have an opinion on the topic.

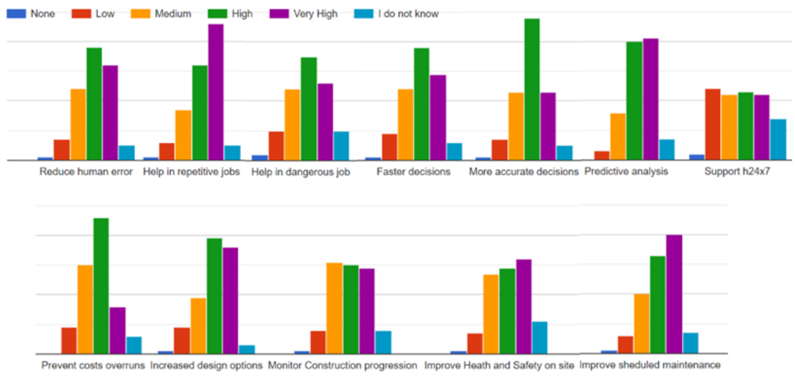


Figure 5. Benefits in using AI in construction

Participants were also asked to add any additional benefits that were not identified before. Those include: process automation and optimization, consumption prediction, capturing more reliable as-built documentation for operation, connection and integration to services outside of construction industry, responding to an issue using telemetry, reduced time of design and construction, reduced costs and use of materials, reduced waste/energy/carbon, increased profit, productivity and efficiency, knowledge capture and knowledge sharing especially using lessons learned to inform new projects. Additional benefits deal with increased compliance between requirements and deliverables, increased collaboration among different parties, generative design, increased creativity during design, increased customer expectations, addressing skills shortage, improved quality of products. It was also mentioned that AI in construction can reduce re-work, improve staff wellbeing by reducing time required to undertake a specific task, increase bid winning, provide schedule certainty, support risk management, and make prediction/resource-re-allocation based on Weather Patterns. AI can also help to finding data quicker, automating interoperability requirements, reduce frauds, allow predictive maintenance and reduce exposure to hazardous activities.

4.2.4 Risks in using AI in Construction

Current literature review on AI in construction lacks a critical analysis on risks. Therefore, participants were asked to evaluate different risks previously identified in other sectors: loss of jobs, privacy violation, algorithmic biases caused by incorrect data, reliability of outputs, inequality, physical safety, financial performance, security, ownership of data, licensing of data and liability. For each risk, participants were asked to use a scale between none, low, medium, high, very high and I do not know. Figure 6 shows the results of the survey. Most of high/very high risks have been identified for ownership of data, licensing of data and liability. The algorithmic bias by incorrect data is perceived at high risk. Medium-high risk has been identified for the reliability of outputs. Medium-low risks are perceived for inequality, security, and financial performance. Privacy violation has a homogeneous distribution from low to high scale. Low risks have been identified by the majority for loss of jobs and physical safety. Those two later aspects are also the ones with higher number of none risk perceived.

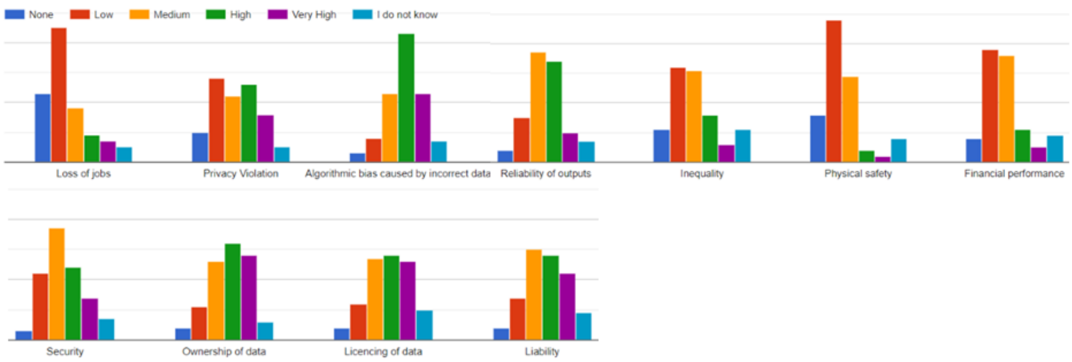


Figure 6 Risks in using AI in construction

Participants were also asked to add any additional risks that were not identified before. Those include the cost of implementation that can cut many companies out, data corruption, availability of reliable data to be used as an input. Several participants also mentioned that by using AI, humans can stop thinking and take decisions without interrogating results, loss of control over automation, lack of emotions in decision making, alienation and loss of applied human knowledge. This can lead in risks in changing culture and mindset. Other participants remarked the risks of intellectual property, liability, and responsibility in case of errors or inaccuracies. Another risk mentioned deal with increased costs due to upper management not understanding how to use the tools within correct workflows and departments. For example, new tools will require new departments to implement them, this will create bloated company structure, reduced profits, inter-department mistrust and rivalry. In addition, data corruption and unexpected data usage are perceived as risks as well lack of consistency in updating the. As AI is something relatively new in the industry, the inexperience and low data literacy can lead to wrong and senior staff might not providing sufficient oversight and governance. Lack of skills and de-skilling are equally perceived as risks. Non-traditional competition entering the market, unknow unknows are also considered a danger. In addition, unfair competition can happen due to overselling the benefits of AI initially in an immature market and over reliance on AI. There can be also a disadvantage for SME's which do not have the competence or resources to implement AI and thus a monopoly is established. Ethical aspects have been also remarked including the risks of having nefarious actors/companies programming, appropriating, and leveraging AI solutions. Finally, AI can increase production that may cause more environmental damage by the construction industry although it can reduce waste.

4.2.5 Additional remarks on AI in construction

Finally, participants had the possibility to add any additional remarks on the topic. Most of them did not have anything to add, but some were really positive mentioning that AI has a great potential in the construction and they are exciting on that. In addition, a lack of a comprehensive Government supported ML/AI strategy for construction (including infrastructure) is restricting the use of ML/AI. The benefits are often not recognised or understood by decision makers and as a result focus is on more day-to-day activities.

On the other hand, others were more cautious and stated that AI is still very new to the industry as a whole; it will need to be vigorously tested and proven with all biases removed through peer review (peers taken from all races/genders/disciplines etc.) before it will be sufficiently trusted to be accurate and reliable. It will also need to be provided with in-built digital safeguarding to prevent it learning beyond it is designed purpose in alignment with all agreed ethical standards. These ethical standards must be in place before any AI is rolled out as a product.

Others underlined both the aspects saying that the opportunities and risks are both very high. But various forms of AI will become pervasive anyway. It will keep on revolutionizing all processes and will change the shape of construction industry utterly, with extreme effects for winners and losers.

In addition, it was said that to effectively use AI/ML in the near future, the standardization of data formats will be critical to allow ML algorithms to create ML models. Without the big data, AI/ML will be limited to machine vision techniques which are limited and does not help in creating Robotic Process Automations which the Construction sector needs. It was also pointed out by one professional that in everyday work AI does not show yet, most of the AI applications are still on very early stages/only in research phase.

4.3 Discussion

The survey results shows that the application of AI in the most advanced construction practices is still limited. Professionals believe that the industry is more advanced that their actual companies. The areas of application are aligned with the ones identified in the literature review. The survey underlines that currently most applications of AI are mostly during design and they deal with process automation and process optimization.

The organizations implementing AI are mainly developing their own products by having a dedicated team and the main application of AI is currently ML.

The benefits identified are aligned with the ones identified in the literature review, with the addition of few aspects including the implementation in bidding.

On the other hand, professionals identify several risks that are aligned with the ones identified in other sectors such as privacy violation, equality vs monopoly, cybersecurity and ethical aspects such as algorithmic bias. Those risks were not previously highlighted in the literature related to the construction sector.

5 Conclusion

AI does appear as a key topic capable to dramatically enhance the productivity of the construction sector over the various stages of the projects. Nonetheless, a deeper analysis of the numerous technologies pertaining to AI entails that the domain should reach a more advanced digital maturity. Such a remark has been confirmed by scientometric reviews (Darko et al. 2020; Pan and Zhang 2021), which were highlighting how risks in using AI in the construction sector were not investigated yet. Despite the adoption in the industry is still limited, even in the most advanced construction practiced, professionals would like to invest in such technology to mainly improve their productivity and manage sustainability aspects. However, on the other hand, practitioners have identified several areas of risks that should be addresses by policy makers.

Constructions is where the barriers between digital and physical are becoming increasingly blurred, and it where the boundary between public and public spaces is fading. People are tracked both outside as part as smart city projects and inside their own homes and offices (through smart appliances from Alexa to smart fridges and remote surveillance) (Bartoletti 2020). The construction sector cannot absolve itself from considerations about risks in AI. The EU AI Act (European Commission 2021b) is therefore welcome as it establishes a framework of controls around risks and harms to individuals. Nevertheless, the sector must understand and embrace the concept of ethics and impact of AI as it plays a crucial role in shaping the norms around the way we live and interact with each other.

5.1 **Key Findings and Impact**

The paper has identified a gap in literature in defining the potential risks associated to the use of AI in the construction sector. In addition, the contribute to knowledge deals with presenting the current implementation in the most advanced construction practices and definition of perceived benefits and risks. Results can help to better understand the needs of the construction community in terms of AI. The findings can be used by academia and industry to develop solutions and by policy makers to create frameworks to measure risks of implementation.

5.2 Limitations and Future work

Data have been collected from construction sector practices that have already implemented digital tools and have been recognized nationally and/or internationally for their achievements. The dataset does not represent the application of AI in the entire construction sector. The adoption of technology can change in a short time framework, especially in unstable situations such as pandemics. Data has been collected during a global pandemic and it is relevant to notice that due to lockdown, companies are sometimes forced to adopt new approaches to face challenges situations such as the impossibility to work on site or the need to reduce resources. For this reason, data should be collected periodically to monitor the progress of the phenomena. Finally, a framework to measure risks of AI implementation in construction should be established.

References

Balabanian, Norman. 2006. "On the Presumed Neutrality of Technology." *IEEE Technology and Society Magazine* 25(4): 15–25.

Bartoletti, Ivana. 2020. *An Artificial Revolution. On Power, Politics and AI.* Indigo Press.

Darko, Amos et al. 2020. "Artificial Intelligence in the AEC Industry: Scientometric Analysis and Visualization of Research Activities." *Automation in Construction.*

European Commission. 2021a. *Annexes To The Proposal For A Regulation Of The European Parliament And Of The Council Laying Down Harmonised Rules On Artificial Intelligence (Artificial Intelligence Act) And Amending Certain Union Legislative Acts*.

European Commission. 2021b. *Regulation of the European Parliament and of the Council Laying down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending Certain Union Legislative Acts*.

ISO. 2018. *ISO 19650-5 Organization and Digitization of Information about Buildings and Civil Engineering Works , Including Building Information Modelling (BIM) - Information Management Using Building Information Modelling. Part 5: Security-Minded Approach to Info*.

Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., E. Oñate. 2021. "Methodological-Technological Framework for Construction 4.0." *Archives of Computational Methods in Engineering volume* 28: 689–711.

Pan, Yue, and Limao Zhang. 2021. "Roles of Artificial Intelligence in Construction Engineering and Management: A Critical Review and Future Trends." *Automation in Construction.*

Poleg, Dror. 2019. *Rethinking Real Estate: A Roadmap to Technology's Impact on the World's Laargest Asset Class*. Springer.

Rafael Sacks, Chuck Eastman, Ghang Lee, Paul Teicholz. 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*. 3rd ed. John Wiley & Sons, Inc.

Sacks, Rafael, Mark Girolami, and Ioannis Brilakis. 2020. "Building Information Modelling, Artificial Intelligence and Construction Tech." *Developments in the Built Environment* 4(May): 100011.

Sawhney, Anil, Mike Riley, and Javier Irizarry, eds. 2020. 53 *Construction 4.0. An Innovation Platform for the Built Environment*. Routledge.

Sharma, Sparsh et al. 2021. "A Survey on Applications of Artificial Intelligence for Pre-Parametric Project Cost and Soil Shear-Strength Estimation in Construction and Geotechnical Engineering." *Sensors* 21(2): 463.

Trine Antonsen, Erik Lundestad. 2019. "Borgmann and the Non-Neutrality of Technology." *Society for Philosophy and Technology Quarterly Electronic Journal* 23(1): 83–103.

Zhou, Peng, and Nora El-Gohary. 2021. "Semantic Information Alignment of BIMs to Computer-Interpretable Regulations Using Ontologies and Deep Learning." *Advanced Engineering Informatics.*