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Digital Asset Management enabling technologies: a bibliometric analysis

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Abstract

Asset Management (AM) is a core function to be implemented for achieving the organisational objectives through balancing risk, opportunities and costs. AM has become more and more relevant, both for producing value through management of the built environment and for supporting the sustainability strategies, ensuring a high-quality built and natural environment to the next generations. Moreover, the Architecture, Engineering Construction and Operations (AECO) sector, mimicking other industries, is shifting from selling products to selling services (Servitization) and this makes AM more and more important. In the last years, following the trend of the digital revolution, a rush to Information Technologies (ICTs) adoption has occurred in AECO, requiring a transition from the AM to the digital AM. Also, this is due to the flourishing standard and literature production on the benefits coming from the adoption of digital system for the management of the built environment. However, still a clear understanding of the potential of the adoption of different ICTs for supporting the core digital AM functions (Risk, Value, Facility management, etc.) has to be defined. This study strives at providing a comprehensive bibliometric analysis in the Scopus database on the use of the most acknowledged disruptive ICTs in different core (digital) AM functions. The bibliometric analysis allows to investigate the literature and to identify the more fruitful semantic fields on which concentrate the next research efforts in studying and developing effective digital AM system for enhanced decision making. The article concludes with a research agenda on information management for improved digital AM.

1. Introduction

Architecture, Engineering, Construction and Operations (AECO) sector has a key role in the European Union (EU) economy, providing 18 million direct jobs, i.e. more than 6% of European employment, and generating about 9% of gross domestic product (GDP) [1]. However, unlike

other sectors (e.g. manufacturing, automotive, healthcare etc.), AECO is struggling to embrace the advantages derived from recent technologies [2], showing a slow rate of digitisation [3]. The AECO, despite being an idle sector, in the design phase already relies on digital tools (e.g. and Finite Elements Method – FEM softwares and Building Information Modelling – BIM), whereas both construction and use (including decommissioning) phases lack in the adoption of new Information Technologies (ICTs) and methods based on digital tools [4].
Nevertheless, the digitisation of the built environment and the related management processes, is seen as a major factor in the innovation of the AECO sector [5]. The digital innovation could bring efficiency and advancement in the design and management processes, and is an enabler triggering a set of new dynamics. One of the most relevant concerns the servitisation [6], namely the shifting from a selling just the product to the final user (in this case the physical asset) to a service-oriented approach concerning the selling of the physical asset within a set of services that can be activated after the purchase. The servitised asset directly impacts on the organisational core business and moves forward in the life cycle (to the use phase) a large part of the value generation [7]. Therefore, the management processes should be improved and upgraded for facing the new needs produced by the digitisation and the servitisation of the built environment.
Within this context, the use and the spread of new disruptive technologies and the integration of physical assets in the digital environment could bring innovation in process management in AECO. The data and information generated are transforming the Asset Management (AM) discipline [8], into digital AM [9]. The trend is evident in Operations Maintenance and Repair (OM&R) services, to be delivered to the client jointly with the physical assets, although the same servitization process could apply to the wide array of services concerning the built environment, up to the level of the urban precincts [10].
With increasing industry interest, a review of the current literature on disruptive technologies adoption in AM is needed. The study presented in this paper strives at providing a better understanding about the dissemination of each main technology category within each digital AM core functions through a bibliometric analysis. Bibliometric is defined as “the statistical analysis of books, articles, or other publications” [11].
The aims of this research are: 1) to provide a better understanding of the current state of art in AM and the technologies that could change it in digital AM; 2) to identify knowledge gaps and introduce a research agenda for further improvements in the digital transformation of the management of the built environment.

2. Methods

The bibliometric analysis allows has been accomplished according to Fig. 1. At first the keywords concerning the core digital AM functions and the disruptive ICTs have been defined (Tab. 1 and Tab. 2). Then, for each function and each technology the Scopus database has been queried with combinations the defined keywords. Eventually the retrieved data have been used for accomplishing the bibliometric analyses presented in section 3.
AM functions have been defined differently in literature [12-13]. However, currently some core functions can be identified as summarised in Tab. 1. These functions result from the investigation,

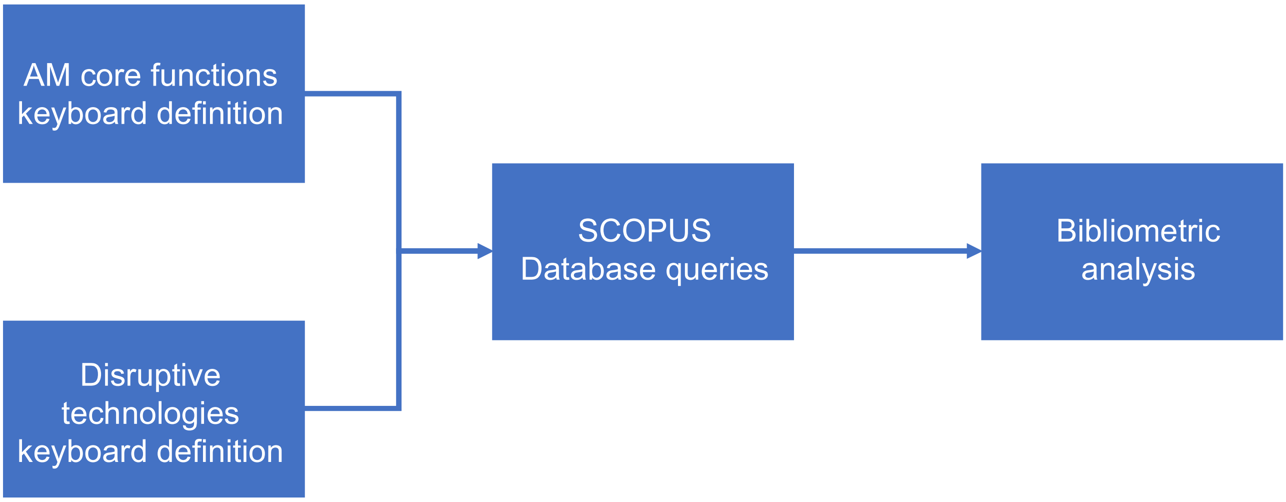

Fig. 1. Bibliometric research workflow.

accomplished in the last year as part of a wider research, of the AM discipline according to a process-oriented approach, allowing to identify main functions, transformations, input and output for each core function [14].

For space reasons here is summarised and presented only a small part of the work, namely the definition and organisation of the core functions according to the decision making level. Strategic functions are those connected to the long-term objectives of the organisation and strictly related to the core business. Tactical functions encompass processes aimed at managing issues on the medium-term horizon and act as a connection between the operations and the strategic AM functions. Eventually, operational functions comprehend processes implemented for realising short terms objectives and day to day tasks. They are the closest to the capacity value [15] of the assets and they are strictly connected with services delivered to the final users. For each core digital AM function, the keywords for carrying out the searches in Scopus database have been defined. For bibliometric analyses [16], Scopus can be considered one of the most acknowledged and reliable databases. The keywords are collected in Tab. 1.
Once the keywords for the core functions have been defined, the disruptive technologies allowing the innovation in AM have been defined. This phase involved the analysis of the classes defined by the Joint Research Centre (JRC) report titled "Digital Transformation in Transport, Construction, Energy, Government and Public Administration" [1] (Fig. 2). The JRC defines classes that, despite being comprehensive of a large amount of technologies, need to be redefined and improved (Tab. 2). The first class, for instance, "Data Acquisition" comprehends the technologies "Internet of Things (IoT) and Sensors". However, the IoT is an approach employing sensors and actuators for automating interconnected features in the built environment. Data produced during this process can eventually been used for improving decision making [17]. Therefore, the sensor, both as a technology and as a research key in Scopus, can be comprehended in the Internet of Things category in Tab. 2. A further example concerns the "Distributed Ledger Technologies (DLT)" that have not been even considered in the JRC report. However, these approaches, out

Core AM functions	*Keywords*
Strategic functions	
Risk Management	(“risk management” or RM) and (building or asset or “built environment”)
Sustainability Management	(“sustainability management” or sustainability) and (building or asset or “built environment”)
Financial Management	“financial management” and (building or asset or “built environment”)
Value Management	“value management” and (building or asset or “built environment”)
Quality Management	“quality management” and (building or asset or “built environment”)
Tactical functions	
Resilience Management	(“resilience management” or resilience) and (building or asset or “built environment”)
Life Cycle Costing	(“Life Cycle Costing “ or LCC) and (building or asset or “built environment”)
Energy Management	“energy management” and (building or asset or “built environment”)
Property Management	“property management” and (building or asset or “built environment”)
Facility Management	(“Facility Management” or FM) and (building or asset or “built environment”)
Operational functions	
Commissioning Management	(“Commissioning”) and (building or asset or “built environment”)
Project Management	(“Project Management”) and (building or asset or “built environment”)
Data Management	(“Data Management”) and (buildings or asset or “built environment”)
Condition Inspection & monitoring	(“Condition Inspection*” or “Condition Monitoring”) and (building or asset or “built environment”)

Tab. 1. List of the keywords used for the Scopus research on each of the core AM functions.

of which the most famous is the Blockchain, have a strong innovation potential in the disintermediation of the transactions among parties in the AM functions [18]. Therefore, they have been considered as a whole technological category in the bibliometric analysis.
Tab. 2 contains all the disruptive technologies for the research and the related keywords. It must be considered that only innovative technologies’ categories (appeared in AECO approximately in the last 20 years) have been considered. Moreover, the keywords have been chosen to catch both the technology analysed and the field of interest, i.e. the built environment. This has been done for

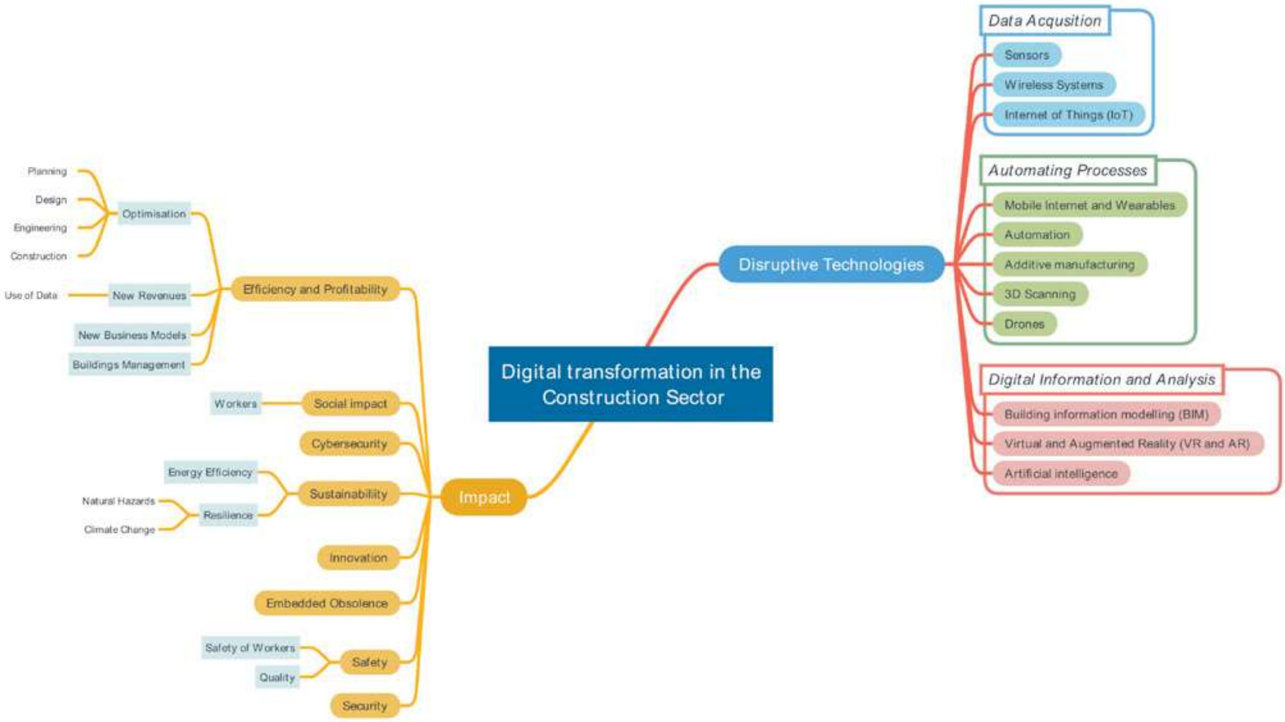

Fig. 2. Digital transformation in the construction sector identified in this work. Image taken from Baldini G, Barboni M, Bono F, et al (2019)[1].

retrieving from Scopus a sufficient number of articles, representing the semantic areas analysed. This is the case, for instance, of the list of keywords employed for the BIM category: the digitisation keywords have been used since they represent the aim of the BIM adoption in AM. Indeed, when the focus is the digital asset, the geometric and location data can be considered as the pivot on which other data types can be anchored.
Besides, authors are well aware of the fact that the term BIM refers to an expansive knowledge domain within the AECO industry [19] and not to a technology. However, the term (set of) technologies is the one that best describes most of the keywords used and therefore has been adopted, by extension, even in cases where it would not be the most appropriate.

Once the set of keywords have been defined, the Scopus database has been queried. Each query was created joining the keywords of one AM function to the ones of a set of technologies. The results of the query were collected in two ways: a) the number of publications found was saved and, afterward, used to create a summary table (Tab. 3); b) bibliometric data of each article were saved in a database for further analysis. This allows to carry out the bibliometric analyses and visualisations, as represented in section 3.

The last step concerns the identification of the most "transversal" or "pervasive" technologies (Fig. 5). For doing this, for each article within the same set of technologies, the AM functions' keywords have been searched. If one article refers to keywords belonging to two or more core

Set of technologies	*Keywords*
Internet of Things	"Internet of Things" or IoT or Sensor* or wearable*
Communication Technologies	"Mobile internet" or "Wireless system*" or "communication network*" or 4G or 5G
Data acquisition	"Point* cloud*" or "laserscan*" or "3D Scanning" or lidar or "remote sensing" or Drones or "unmanned aerial vehicles" or UAV*
Blockchain	Blockchain or DLT or "distributed ledger technology*" or "Smart contract*"
BIM	(BIM or "Building Information Modelling" or "Building Information Modelling" or Digitalization or Digitalisation or Digitisation or Digitization)
Augmented and Virtual Reality	("Augmented Reality" or "Virtual Reality" or "Mixed Reality")
Artificial Intelligence	("Artificial Intelligence" or "Machine learning" or "Artificial Neural Networks" or ANN)
Additive manufacturing	"Additive manifacturing" or robot* or "3D printing"

Tab. 2. List of the keywords used for the Scopus research on each technology.

functions, the set of technologies the article belongs to is considered pervasive. This analysis informs on the innovation/application potential of the considered technologies in the core AM functions. The analysis does not consider the number of core functions appearing in the article, i.e. an article dealing with two AM function is as pervasive as one dealing with three, four or even more set of technologies.

3. Bibliometric analyses results and discussion

This research uses bibliometric analysis in order to review existing literature dataset on different technologies set for digital AM. The keyword search methods explained in section 2 were employed to identify relevant articles in journals and conference proceedings. The results of Scopus database querying have been summarized in Tab. 3.

Digital AM core functions analysis

The total amount of publications for each digital AM core functions is presented in Fig. 3, where the histograms are given by the sum of articles for each row in Tab. 3. The function with more contributions is Project Management (PM), which is strictly correlated with BIM technology, since this function has been one of the first to be engineered [20]. Noteworthy, strategic, tactical and operational functions present similar number of publications, which means that the disrup-

		Internet of Things	Communication Techno-logies	Data acquisition	Blockchain	Building Information Modeling (BIM)	Augmented and Virtual Reality	Artificial Intelligence	Addictive manufacturing
Strategic functions	Risk Management	183	41	153	9	121	31	185	41
	Sustainability Management	411	36	143	16	522	70	299	95
	Financial Management	1	14	0	1	2	4	25	2
	Value Management	0	0	0	1	12	0	1	0
	Quality Management	47	5	22	3	56	11	48	20
Tactical functions	Resilience Management	198	44	70	10	40	36	122	39
	Life Cycle Costing	13	0	4	0	45	2	18	8
	Energy Management	986	63	32	10	109	24	452	67
	Property Management	11	0	2	1	16	2	2	2
	Facility Management	239	12	123	4	612	93	98	246
Operational functions	Commissioning Management	157	4	14	0	43	19	32	21
	Project Management	199	27	116	8	1071	169	209	192
	Data Management	345	21	99	19	188	39	120	29
	Condition Inspection & Monitoring	421	23	43	2	21	5	114	29

Tab. 3. Number of articles resulting from the Scopus research using the combination of keywords in Table 1 and Table 2.

tive technologies are spread transversally (even if some core function presents few contributes). Finally, Value, Property and Financial Managements, which are more directly involved in the economic aspect of AM, present very few articles, therefore a bigger commitment in those functions could be addressed.

Technologies analysis

The pie chart presented in Fig. 4 shows the percentage of papers of each set of technologies related to the total number of publications considered in this study. The most explored technology is Internet of Things (IoT), which aims to equip all built environments' entities with sensing, identifying, networking and processing capabilities [21]. The analysis in Fig. 4 confirms the IoT dissemination also in-built AM besides the already ascertained usage in manufacturing.
Unsurprisingly, BIM is the second technology for number of publications, since it has been the

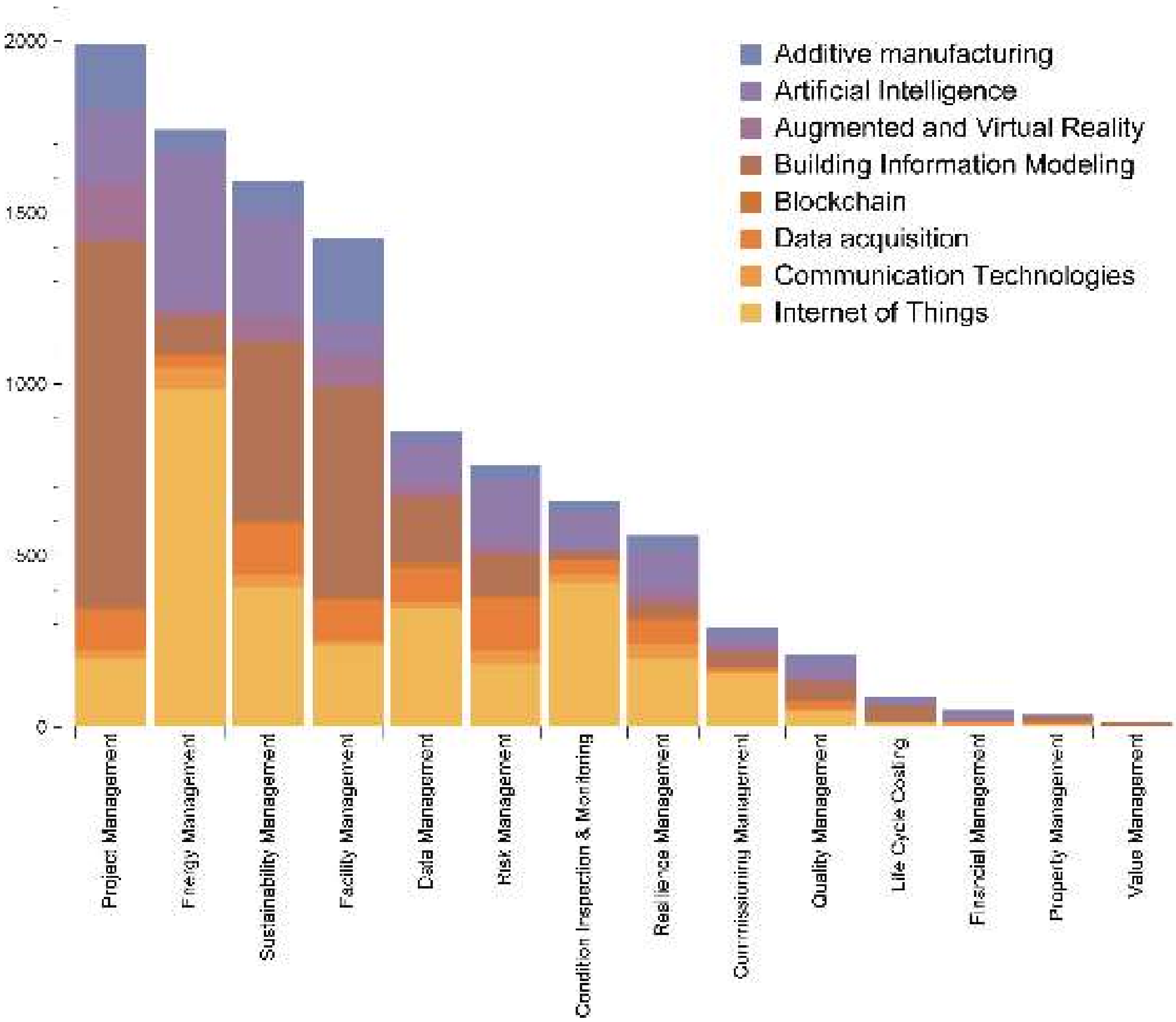

Fig. 3. Number of articles for each core AM function divided by technology set.

first step in the digitalization process and it is the technology that presents the most mature background inside the field [22].

The graph in Fig. 5 illustrates the pervasiveness of a technology on multiple AM functions. Pervasiveness is measured as the ratio, for each technology, between the number of articles concerning more than one AM function and the total number of articles. It provides a measure of how “transversal” a technology is.

The pervasiveness of articles on BIM is almost double the average of all articles which is 7.55%. This is probably a consequence of the large number of publications concerning the BIM methodology implementation (possible and actual) in the AECO sector.

Blockchain and DLT, despite being much newer technologies than BIM, show a high pervasiveness (around 9.52% of the average), which is likely to increase as the technology matures [18] poor regulation and compliance, lack of adequate collaboration and information sharing, and poor payment practices. Advances in distributed ledger technologies (DLT). Indeed, Blockchain has been

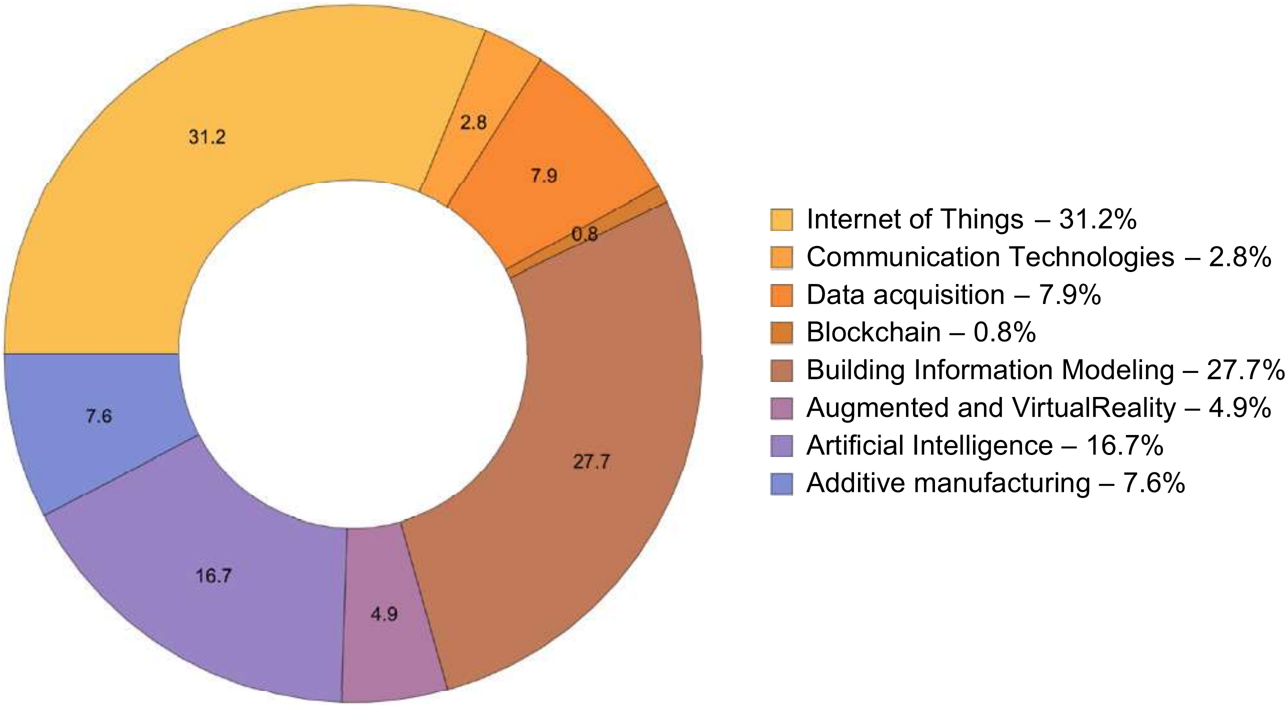

Fig. 4. Percentage of articles for each set of technologies used in AM.

mostly linked with Cryptocurrency and only recently this technology started to be investigated in other fields [23].

Finally, the AI technology set presents a high number of findings and a good pervasiveness among all the DAM core functions, which is relevant considering how new is the application of this disruptive technology to the AECO sector and his fast spreading in different sectors. In particular, Artificial Neural Network (ANN) [24] and Computer Vision [25, 26] techniques, seem to be the most interesting AI application in Construction industry.

4. Conclusions

The rise of new disruptive technologies and the potential of the new hardware linked with the easier possibility to collect big dataset, have opened up new horizons for progressively changes in buildings, communities and cities, leaded by the digitalization processes. This paper provides a comprehensive bibliometric analysis on the use of the most acknowledged disruptive ICTs in different core digital AM functions, which give us a holistic perspective about the current state of digital transformation in management of the built environment.
However, some limitations can be highlighted. To improve the number of articles analysed Web of Science (WOS) database could have been used, despite Scopus collects more findings, while researches conducted by means of Google Scholar dataset are not reliable [27]. Moreover, the findings are circumscribed by the initial selection of keywords and thus the coverage of the current literature might be limited.

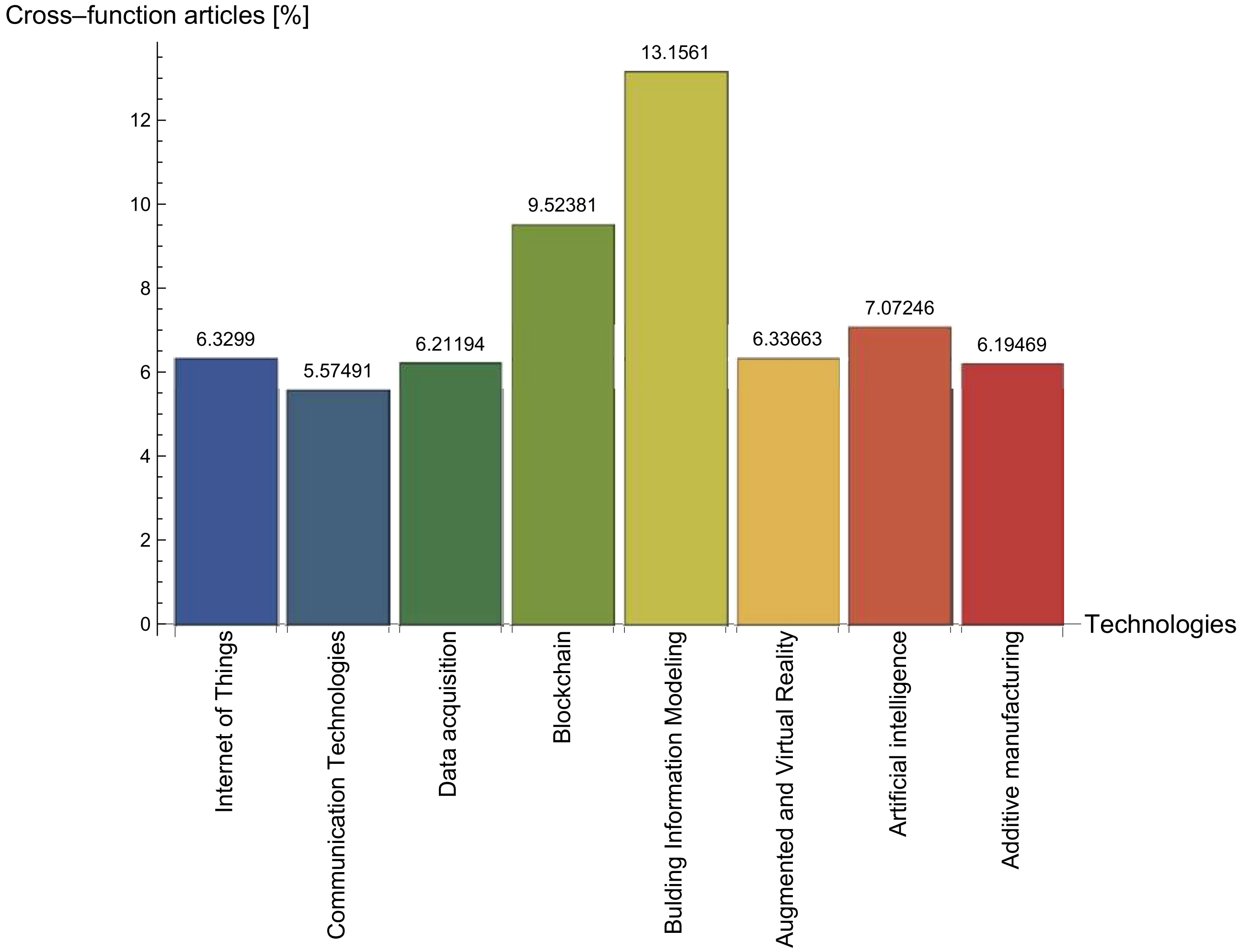

Fig. 5. Percentage of articles dealing with one technology and more than one AM functions.

From Section 3, the most fruitful semantic fields on which concentrate the next research efforts in studying and developing effective digital AM system for enhanced decision making can be identified. It is evident from these results that BIM has a key role in the digital transformation: since the UK BIM mandate in 2011, every European country is pushing towards BIM adoption.

This is proved also by the fact that many EU member countries already have legislations on BIM (e.g. see [28] in Italy) and by the intense standardisation work made by the Technical Committee CEN/TC 442 – Building Information Modelling (BIM) at the European Committee for Standardisation (CEN) [29-31].
BIM, together with IoT and AI, is evolving from his primitive concept to a completely new one called Digital Twin [32, 33]. In the bibliometric analysis, AI, in particular, presents a good number of findings that, differently than IoT, belong to more than two functions (Fig. 5). This suggests the versatility and pervasiveness of the technology. The evolution of AI and Machine Learning techniques increase dramatically in the last 10 years [34] starting from the first linear regression algorithms to the newest Deep Neural Networks. Finally, DLTs presents few citations (Tab. 3),

however in Fig. 5 it is evident his pervasiveness among different digital AM core functions, which means that the topic is still new but the interest is high.

A possible next step of the research highlighted in Table 3 and Figure 3 and concern the low connection between decision-making functions (i.e. Value, Property, Financial Management) and the disrupted ICTs observed/analysed. The Table 3 and Figure 3 highlight how the decisional aspects of the economic-financial spheres seem to be disconnected from ICTs more employed in technical AM functions. This aspect certainly needs further study and could open cross-disciplinary research scenarios.

The following steps of this study could consider conducting further bibliometric analyses like network analysis and historical series, since we are facing new technologies and could be interesting consider their dissemination over the time.

To extend the current research agenda, starting from the concept of Industry 4.0 and its implications with respect to the digitalization of the AECO sector [35], future researches may target the integration of IoT networks with AI techniques in order to reach a new level of connectivity and interoperability, along with a real-time updating BIM.

In the face of digital transformation, the application of new disruptive ICTs will remain a relevant area of research. Advances in this field will requires the joint efforts of practitioners and academics in order to deal with these challenges.

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