A Systematic Mapping Study on the Role of Software Engineering in Enabling Society 5.0

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***Abstract*—Society 5.0 is a visionary project aimed at creating sustainable smart societies, which relies on advanced computer science and software engineering techniques. Hence, software engineering plays a critical role in enabling Society 5.0 by providing the necessary technological advances and practices to address societal issues.**

This paper presents a systematic mapping study that focuses on identifying the key software engineering technologies and challenges that are critical for achieving the goals of Society 5.0. The study begins with an initial set of 1646 peer-reviewed publications, from which a final set of 29 primary studies was selected through a rigorous selection process. The selected studies were subjected to meticulous data extraction, analysis, and synthesis. The primary studies identified 13 software engineering technologies that act as enablers of Society 5.0. However, the application of these technologies also comes with technical challenges. The selected primary studies identified ten software engineering open challenges that hamper the realisation of Society 5.0.

The findings of this study have important implications for software engineering researchers and practitioners involved in developing sustainable smart societies. The identification of the key technologies and challenges in Society 5.0 can help guide future research and development efforts in this field.

***Index Terms*—Software engineering, Society 5.0, Industry 5.0, systematic mapping study.**

I. Introduction

The Japanese Council for Science, Technology and Innovation (CSTI) introduced Society 5.0 [1] as a way of addressing critical societal issues such as reducing greenhouse gas emissions, traffic-related deaths, and enabling early disease detection across various sectors, including medicine, and mobility [2]. Society 5.0, which emerged in 2016, builds upon previous projects like Industry 4.0 [3]. While Industry 4.0 focuses on the benefits of using automation to enhance efficiency, customer orientation, and speedy manufacturing, Society 5.0 seeks to create an advanced society that prioritises the well-being of its citizens by placing people at the center [4]. Achieving this objective necessitates the use of cutting-edge technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Augmented Reality (AR), Virtual Reality (VR), and robotics. It is crucial to comprehend the role of software engineering in the implementation of Society 5.0 and how it differs from earlier projects such as Industry 4.0 from a software engineering perspective, given the novelty of Society 5.0.

This paper presents the first mapping study on the relationship between Society 5.0 and software engineering, based on an analysis of 29 primary studies selected from an initial set of 1646 peer-reviewed publications [5]. The study found that the first peer-reviewed publication on software engineering for Society 5.0 appeared in 2018, and there has since been a considerable increase in the quantity and quality of publications on this topic. The most frequently mentioned software engineering technologies enabling Society 5.0 were found to be AI, IoT, and Internet of Everything (IoE), although several challenges were identified, such as data protection, connectivity, and interoperability. Data security was identified as the most significant challenge among the ten open challenges considered. Furthermore, the application of AI, IoT, and IoE in Society 5.0 presents unique challenges. The study also revealed that Society 5.0 employs five technologies not used in Industry 4.0, including empathetic and collaborative robots and IoE. However, several technologies from Industry 4.0, such as IoE, are being expanded upon in Society 5.0. The research contributes to the ongoing debate on the evolution of Industry 4.0 and the potential of Society 5.0, by providing a comprehensive understanding of the software engineering technologies enabling Society 5.0 adoption and identifying critical software engineering challenges associated with the project.

The paper is organised as follows. Section II explains the research methodology and validity threats. Section III presents the results of vertical and orthogonal analyses. Section IV discusses the main findings and differences between Society 5.0 and similar initiatives. Section V reviews related literature. Finally, Section VI concludes the paper with final remarks and suggestions for future work.

II. Research methodology

We designed and conducted this research using the guidelines for systematic mapping studies in software engineering proposed by Petersen et. al. [5]. Figure 1 depicts the adopted methodology. During the planning phase, we created

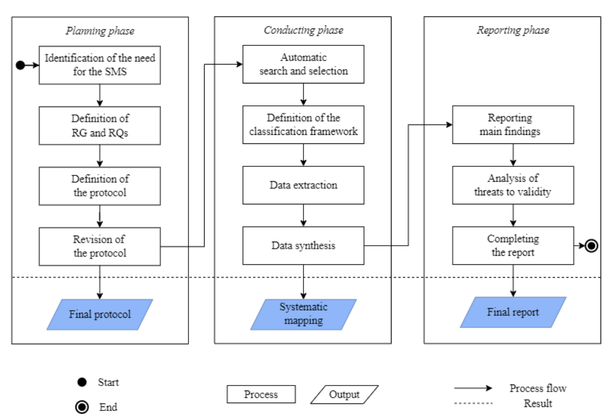

Fig. 1: Overview of the process [5]

a research protocol to guide our systematic mapping study. In the conducting phase, we conducted an automatic search on reputable scientific databases [5] using a set of selection criteria defined according to Ali and Petersen's guidelines [6].

We also performed closed-recursive backward and forward snowballing to enhance the search [7]. We built a classification framework using the key wording method and used it to analyse the primary studies and extract data [5]. We then conducted vertical and orthogonal analyses on the extracted data to answer our research questions. In the reporting phase, we documented the study, its steps, and its main results. We also reported on potential validity threats and provided a public replication package containing search and selection data, the primary studies list, and data from the data extraction process accessible at https://github.com/vladanaa/Role-of-Software-Engineering-in-Enabling-Society-5.0.

A. Research goal and questions

Using the Goal-Question-Metric method [8], we defined the research goal (RG) that is summarised in Table I. We

Purpose	Identify, classify, and evaluate
Issue	publication trends, enabling software engineering technologies, and open software engineering challenges
Object	of Society 5.0
Viewpoint	researchers and practitioners in Society 5.0 and software engineering

TABLE I: Research goal expressed using the Goal-Question-Metric method

refined the above RG into specific research questions (RQs) as follows.

RQ1:Which are the publication trends in software engineering for Society 5.0? By answering RQ1, we quantify the number of studies across years, venues and venue types.

RQ2:Which are the main software technologies enabling Society 5.0? By answering RQ2, we provide a catalogue of the software engineering technologies that are pivotal for the realisation of Society 5.0, and exemplify their application.

RQ3:Which are the current software engineering open challenges hampering the achievement of Society 5.0? By answering RQ3, we identify and describe the main software engineering challenges affecting the realisation of Society 5.0.

B. Search and selection process

Figure 2 shows the steps we followed to obtain the set of primary studies. We started with automatic search on four scientific databases and indexing systems in software engineering [9], which are: IEEE Xplore Digital Library, ACM Digital Library, SCOPUS, and Web of Science. We selected these sources based on their high accessibility and reputation [5]. We exercised the above databases using the following search string:

"Society 5.0" OR "Industry 5.0"

Considering that Society 5.0 is a quite new research area, we used a simple search string that helped us in gathering as many studies as possible. Despite we are aware of several nuances in the terminology as the alternative use of Society 5.0 and Industry 5.0, our experience identifies Society 5.0 as

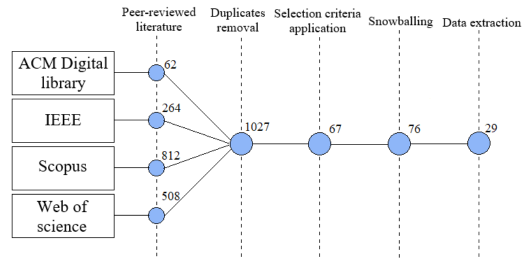

Fig. 2: Search and selection process

the most generic and inclusive one, while the other is used as a specialisation and often mentioned jointly. We discuss threats to validity related to the search string at the end of this section. The initial search produced a set of 1646 peer-reviewed publications. From this set, we removed impurities and duplicates and obtained a new set of 1027 publications. We filtered this set using the following selection criteria that we defined using the guidelines by Ali and Petersen [6].

- Inclusion criteria
  - Studies subject to peer review
  - Studies written in English
  - Studies available as full-text
  - Studies focusing on software engineering technologies and/or challenges
- Exclusion criteria
  - Studies in the form of tutorial papers, short papers (≤4 pages), poster papers, editorials, manuals, because they do not provide enough information.
  - Secondary or tertiary studies.

For a study to be included in following steps, it had to meet all the inclusion criteria and none of the exclusion criteria. The application of the selection criteria led to a new set of 67 potential primary studies. We complemented the automatic search with closed-recursive backward and forward snowballing activities [7]. This resulted in including 9 additional publications for a new set of 76 primary studies.

C. Data extraction

To extract and gather the data from the selected primary studies, we developed a classification framework in Table II. The classification framework consists of three facets, one per research question. RQ1 consists of a cluster containing publication details such as title, and authors. We composed the clusters for RQ2 and RQ3 following the key-wording systematic process Peterson et al. [5]. Hence, focusing on the full text of the primary studies, we gathered keywords for software engineering technologies and challenges that we afterwards grouped into similar categories. During the data extraction, we eliminated 47 peer-reviewed publications from which we could not extract any relevant information and obtained a final set of 29 primary studies listed in the Primary Studies appendix.

D. Data analysis and synthesis

Following the guidelines by Cruzes et al. [10], we collected, analysed and synthesised the data that we extracted in the previous step. We conducted both quantitative vertical and orthogonal analysis combining content analysis [11] and narrative synthesis [12] techniques. During the vertical analysis, we

Facet	Category	Description	Value
RQ1	Publication title	Identifies the title of the publication	String
	Authors	Identifies the authors of the publication	String
	Year	Identifies the year of the publication	Numeric value
	Venue Name	Identifies the name of the publication venue	String
	Venue Type	Identifies the type of the publication venue	Book chapter, journal, conference, workshop
RQ2	Enabling software engineering technologies	List of technologies as identified in the studies	String
RQ3	Open software engineering challenges	List of challenges as identified in the studies	String

TABLE II: Data extraction form.

collected information using the parameters of the classification framework and analysed each of the primary studies independently to provide answers to the RQs. For the orthogonal analysis, we compared categories of the classification framework, for identifying potential trends and patterns [13]. Section III presents the results of the vertical and orthogonal analysis.

E. Threats to validity

When conducting this study, we followed well-established guidelines for systematic mapping studies. These include the definition of a detailed research protocol. However, there is still a possibility that validity threats affected our research [13].

The generalizability of our study could be affected by having a collection of primary studies being not representative of the state-of-art of software engineering for Society 5.0. To reduce this threat, we conducted an automatic search on four of the most well-known electronic databases and indexing systems in software engineering. The selected studies were complemented with closed recursive backward and forward snowballing activities. Finally, we selected peer-reviewed studies focusing on Society 5.0 and software engineering technologies and/or challenges. Throughout the primary studies selection, we excluded studies not written in English. Since English is the *de-facto* standard language for scientific documents in software engineering and computer science, we acknowledge that excluding studies written in other languages than English is a minimal threat to the external validity. The existence of different terms used in place of Society 5.0 might have altered the scope of our search. However, our observed remarks show that the use of different terms is associated with Society 5.0. Consequently, we can be sure that our search covered the scope of Society 5.0. We designed and conducted this study using guidelines for systematic mapping studies in software engineering. This enabled us to reduce possible internal validity threats [13]. Regarding the validity of data, we reduced potential internal threats by employing descriptive statistics and by performing sanity checks on the different categories of the extraction form. These tasks helped us identify and solve potential issues regarding the consistency of the extracted data. As reasoned for external validity threats, the automated search was executed by employing four different databases and complemented with snowballing activities. A poorly-constructed search string could be a potential threat to construct validity. We kept the search string minimal so no particular attention to its construction was needed. In addition, this helped us in being more inclusive in the initial stages. We filtered out the studies using selection criteria, which we constructed using well-established guidelines. To reduce threats to conclusion validity, we continuously and systematically applied and recorded well-clarified procedures for systematic mapping studies. In addition, we provided a complete and public replication package for enabling independent verification and replication of our study.

III. Results

We analysed the primary studies and classified their features according to the classification framework in Table II. It is possible that we extracted multiple values or no value at all from a single study. Hence, the number of occurrences in the graphs may be different from the total number of primary studies.

A. Publication trends (RQ1)

Our data shows an upward trend in research on software engineering for Society 5.0. While Society 5.0 was introduced in 2016, the first peer-reviewed study was not published until 2018 (Figure 3). The number of peer-reviewed publications has steadily increased, peaking in 2022, with 17 out of 29 primary studies published in conferences or journals (Figure 3). We expect this trend to continue in the future. The majority of primary studies (75.9%) were published in journals, while 20.7% were conference papers (Figure 4). Only one primary study was published as a workshop paper. Hence, despite being

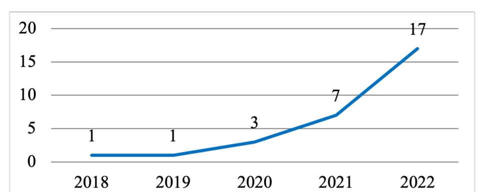

Fig. 3: Publication trend over time

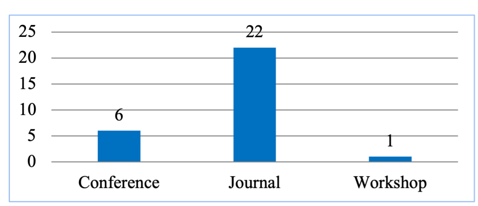

Fig. 4: Publication trend over venue

a relatively recent research area, it seems that research on software engineering for Society 5.0 is well-structured and mature in quality. Our data shows that studies were published in 26 different venues, indicating a highly diverse research community with no specific venue preference. This may be due to the contributions from various computer science and software engineering areas.

> *Highlights – RQ1 Publication trends*
>
> - First peer-reviewed study was published in 2018, and the number of publications on software engineering for Society 5.0 has grown since then.
> - 28 out of 29 primary studies were published as conference or journal papers.
> - Apart from the IEEE Transactions on Industrial Informatics journal, Journal of Manufacturing systems, and Computers & Industrial Engineering no specific venue is favoured by the scientific community.

B. Enabling technologies (RQ2)

Our analysis has identified 13 software engineering technologies, as illustrated in Figure 5, that are essential for the successful implementation of Society 5.0. These technologies have either been explicitly mentioned in relevant publications or inferred from the content of primary studies. Our analysis indicates that AI is the most cited technology, with a mention frequency of 20%. IoT and IoE follow closely, with a mention frequency of 18.9% in primary studies, and are expected to have a profound impact on Society 5.0. Designing cognitive and collaborative manufacturing systems for Industry 5.0 presents a complex challenge due to the unpredictable behaviour of human operators. Successful modelling of safe working systems requires in-depth analysis, safe control strategies, and integration of AI algorithms, as proposed by Gaiardelli et al. [p5]. Edge AI enables collaborative cognitive communication systems, but they cannot function collaboratively like humans. Therefore, 3C systems can enhance the capabilities of AI bots, providing human cognition to operate effectively in more complex environments [p10]. IoE technology plays a crucial role in connecting humans, data, processes, and things and is predicted to be a fundamental element of Society 5.0 [p14]. With the addition of 5G, IoT solutions are envisaged to be of significant importance for the development of sustainable smart cities [p19]. We have also observed that digital twin (DT) and robotics are essential technologies, accounting for 9.4% of primary studies each. DT is expected to surpass traditional solutions in analysis and evaluation, predictive diagnosis, and performance optimization, as stated in P24. Collaborative robots (cobots) are identified as a critical pillar technology for human-robot collaboration. Gosselin et al. describe the concept of a robot companion for robot-aided manufacturing, integrating software engineering and AI functionalities [p20] ML is another technology with significant impact on the realisation of Society 5.0, with 8.4% of primary studies mentioning its use. Various ML algorithms, such as LSTM, KNN, NB, RF, DT, GBM, and CNN, are frequently mentioned in various domains, including human-robot collaboration systems and cloud-based computational frameworks for empathetic robots [p7], [p16]. Combining ML with other technologies, such as IoT, 6G, and blockchain, can have substantial benefits, particularly in collaborative cognitive communication systems [p10] and public blockchain networks, where blockchain can increase validation latency and detect malicious end-users in healthcare systems [p13]. Cloud and edge computing (8.4%) and VR (5.2%) are also key technologies for the realisation of Society 5.0. Integrating cloud computing and AI with drones can improve aquaculture operations by collecting data more efficiently [p27]. Applying cloud-edge computing for end-to-end monitoring of the value chain can improve efficiency and reduce workforce reliance for both menial and high-risk tasks [p27]. Additionally, VR can simulate real-time environmental conditions through digital interfaces like headsets [p27]. Our analysis reveals that these technologies have a significant impact on various domains related to Society 5.0, such as medicine, mobility, agriculture, food, and energy.

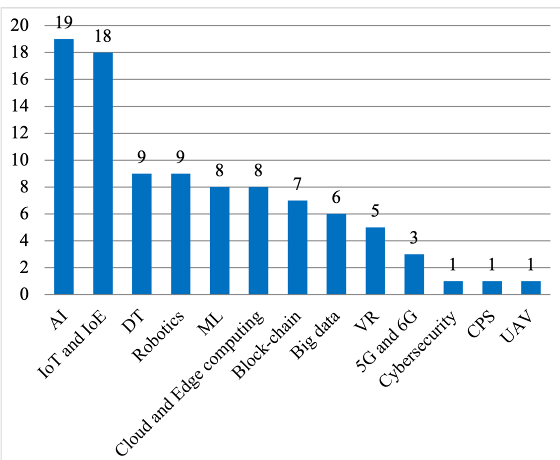

Fig. 5: Enabling technologies

> *Highlights - RQ2 Enabling technologies*
>
> - The study identified 13 critical software engineering technologies that are essential for the successful implementation of Society 5.0.
> - AI is the most cited technology, with a mention frequency of 20%, followed closely by IoT and IoE with a mention frequency of 18.9% in primary studies.
> - DT and robotics are essential technologies accounting for 9.4% of primary studies each, and collaborative robots (cobots) are identified as a critical pillar technology for human-robot collaboration.
> - Combining ML with other technologies, such as IoT, 6G, and blockchain, can have substantial benefits, particularly in collaborative cognitive communication systems and public blockchain networks.

C. Open challenges (RQ3)

As part of our research study, we aim to identify and catalogue the software engineering challenges that may hinder the successful realisation of Society 5.0. Our findings suggest that there are ten significant open software engineering challenges that must be addressed to achieve Society 5.0 (Figure 6). The collected software engineering challenges have either been explicitly mentioned in relevant publications or inferred from the content of primary studies. It

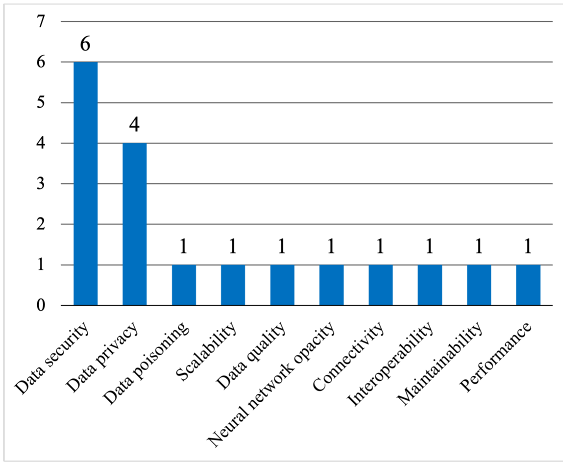

Fig. 6: Open software engineering challenges

is worth noting that most primary studies have primarily focused on applying software engineering technologies instead of investigating the open challenges that may impede the achievement of Society 5.0. Moreover, these primary studies have mainly discussed environmental and societal challenges rather than technical or software engineering ones. We have elaborated on these findings in Section IV of our paper. Our research study has found that the most significant software engineering challenge is data security (33.3%). In Society 5.0, technologies such as block-chain and cloud computing require large amounts of data, including personal and confidential information. However, these technologies are still susceptible to security breaches and privacy concerns. To address this challenge, Yang et al. proposed a user-centric sharded block-chain that allows for the generation, verification, and storage of data blocks [p17]. In addition to data security and data privacy, we have identified a cluster of eight challenges: data poisoning [p23], scalability [p3], data quality [p3], neural network opacity [p3], connectivity [p3], maintainability [p7], performance [p13] and interoperability [p3]. Each of these challenges was reported in only one primary study. Carayannis et al. discuss scalability as an open challenge for block-chain technology as nodes validating transactions need to download the entire block-chain into their machines [p3]. They observed that this will represent a challenge in Society 5.0 applications where the size of block-chains tends to be rather big. Interoperability is defined as the ability of a system to operate with other systems, either physical or cyber ones. In the context of Society 5.0, interoperability appears to be a crucial challenge to be tackled considering the higher number of devices and people that Society 5.0 applications aim at connecting through IoT, industrial IoT, IoE, etc., and their heterogeneity. However, Carayannis et al. suggest that a standardisation for seamless communication among heterogeneous IoT devices is still lacking [p3]. The opacity of neural networks refers to the impossibility of deriving any clear relationship between the interior configuration of the networks and their external behaviour. Carayannis et al. believe that neural network opacity is an open challenge for Society 5.0 application as awareness of neural networks functionality is not sufficient for all professionals and clarifications on given results of neural networks need to be provided [p3]. Another open challenge identified by Carayannis et al. is data quality in the context of deep learning [p3]. For deep learning proficiency, a vast amount of high-quality data is required. How to ensure data quality represents an open issue concerning AI, ML, and DL [p3]. We could not gather any explicit reported data labelled as ethics.

Highlights - RQ3 Open challenges

- Ten significant software engineering challenges must be addressed to achieve Society 5.0, with the most significant being data security.
- Scalability represents a challenge in Society 5.0 applications where the size of block-chains tends to be rather large.
- Interoperability is crucial as it involves connecting numerous devices and people through IoT and IoE with their heterogeneity being an issue.
- Neural network opacity is an open challenge as it is challenging to derive any clear relationship between the interior configuration of the networks and their external behaviour.

D. Enabling technologies vs open challenges

We have conducted a thorough analysis of the correlations between enabling technologies and open challenges. To achieve this, we employed contingency tables and represented the results using a bubble chart (Figure 7). Our

Fig. 7: Enabling technologies vs Open challenges

study identified 13 software engineering technologies and ten software engineering challenges that are relevant to Society 5.0. By examining the correlations between these technologies and challenges, we have made some interesting observations. Firstly, we noticed that certain software engineering technologies have relations with almost all the challenges. Specifically, AI, IoT, and IoE, and block-chain were found to have strong correlations with multiple challenges. Additionally, ML was found to be related to five challenges, namely, data security, data privacy, data poisoning, maintainability, and performance. Conversely, some technologies did not have any relation to any of the identified challenges. These technologies include CPS, and 5G and 6G. This may be due to the fact that these technologies are either too new or too mature, hence the challenges they face are either not yet evident or have already been solved in other domains. Furthermore, we discovered that data security is an open challenge for most of the enabling technologies. This is not surprising, as data security was the most frequently mentioned challenge. In particular, we observed a higher correlation between data security and AI, IoT, and IoE, which is expected since these technologies primarily work with data. For instance, AI algorithms require a large amount of data to be trained, and IoT involves exchanging data between physical objects and systems over the Internet. Managing data in a secure manner is indeed a crucial challenge, as highlighted in P3 [p3]. Lastly, we found that cybersecurity is one of the technologies that can ensure data protection, which is not unexpected. The correlation between cybersecurity and data security is particularly significant in this regard. Overall, our study sheds light on the important role of software engineering in enabling Society 5.0. We hope that the insights gained from our research will aid in the development of effective solutions to the challenges faced by these technologies.

Highlights - Enabling technologies vs open challenges

- Certain technologies (AI, IoT, IoE, and block-chain) have strong correlations with multiple challenges, while others (CPS, and 5G and 6G) have no relation to any challenges.
- Data security is a major challenge for most enabling technologies, with higher correlation observed between data security and AI, IoT, and IoE.

IV. Discussion

Japan has the oldest population in the world, with 26.3% of citizens over 65 years old [14]. Ageing brings societal challenges that affect daily life domains such as mobility and healthcare [15]. In response, the Japanese government presented the project Society 5.0 in 2016, which advocates for the use of software engineering advances such as AI, IoT, digital twin [16], robotics, and ML to improve daily life. Society 5.0 expands beyond Industry 4.0, a German government project focused on improving manufacturing through automation and optimisation, to include domains such as mobility, medicine, food, agriculture, and energy. However, it remains unclear how Society 5.0 differs from previous projects such as Industry 4.0, particularly from a software engineering perspective

Multiple studies have examined the software engineering technologies that enable Industry 4.0. For instance, Martinelli et al. studied this topic and reported a set of six technologies being AI, IoT, big data, cloud manufacturing, robotics, and additive manufacturing [17]. Zheng et al. expanded the set by Martinelli et al. with four additional software engineering technologies being CPS, block-chain, simulation and modelling, augmented and VR [18]. We identified 13 software engineering technologies, which we discuss in Section III. Among these, AI, IoT, and IoE were the most frequently mentioned as critical for achieving Society 5.0. These technologies, like in Industry 4.0, are used to automate routine activities in several fields such as healthcare, mobility, and energy. The selected primary studies reported several examples of applications of AI and IoT within the healthcare domain ([p3], [p6]).

In Society 5.0, the use of IoT is sided with the use of IoE. Maddikunta et al. state that the role of IoE in Society 5.0 is *"to reduce operating costs by eliminating bottlenecks on communication channels, reducing latency, reducing supply chain waste, and optimising production processes"* [19]. Similarly to AI, ML is also widely used for realising advanced medical applications in the context of Society 5.0 ([p7], [p13]). An example is the use of ML embedded intelligent wearable devices for providing personalised treatments [19]. The collaboration between humans and robots has been a pillar of Industry 4.0. Similarly, collaborative robots, also known as cobots [19], are crucial in Society 5.0 for improving safety, productivity, and performance [19]. Maddikunta et al. describe the use of cobots as an aid for performing surgical procedure [19]. In addition to robots and cobots, Society 5.0 is at the forefront of another robotic advance namely empathetic robots [p7]. Salaken et al. believe that empathetic robots *"is one step forward toward (Society 5.0), as it provides a theoretical framework to enable the performance of the robot to be customised to suit the needs of both the task as well as the operator"* [p7]. Comparing our data with the above mentioned studies from Martinelli et al. and Zheng et al., we can conclude that Society 5.0 is characterised by a set of 13 software engineering technologies of which 5 are unique and not shared with Industry 4.0. Besides, we can conclude that there are differences in the use of those technologies that are common among the two projects, as follows. In the context of Society 5.0, AI and IoT are mostly applied in the healthcare domain with IoT being sided/replaced with IoE. Society 5.0 is advancing the use of robots employing cobots and empathetic ones.

The full-fledged adoption of Society 5.0 is hampered by numerous challenges. Our data identifies two main categories of challenges, being technical challenges related to the adoption of software engineering technologies and societal or environmental challenges related to the acceptance of and the impact on society of such technologies. In Section III, we reported on the ten technical challenges mentioned in the collected primary studies: data security, data protection, data poisoning, scalability, data quality, neural network opacity, connectivity, maintainability, performance, and interoperability. Interestingly, most of these challenges were mentioned only in one primary study each. We believe that this can be explained considering that most of the potential technical challenges hampering Society 5.0 have been solved in previous projects like Industry 4.0. For instance, interoperability was already reported as a challenge hampering the realisation of Industry 4.0 n [20], [21]. Among the ten challenges identified in our primary studies, only data security was reported as a challenge by 6 studies. We believe this can be explained considering the importance of data in potentially all the Society 5.0 enabling technologies and related applications. This was confirmed by the orthogonal analysis results that highlighted relations between data security and 9 of the 13 enabling technologies. During the data extraction, we focused on software engineering challenges. However, some studies reported on environmental and societal challenges, too. Notably, social heterogeneity, environmental and social value generation measurement, research disciplines and system complexity interdisciplinarity are examples of such challenges [p9]. One compelling instance is the ongoing debate on the use of language models like ChatGPT that led Italy in becoming the first country to ban the use of such technologies due to concerns over the potential ethical implications of these models.

Comparing our data with previous researches, we can conclude that several of the open challenges hampering Society 5.0 are environmental and societal. Most of the technical challenges potentially impacting Society 5.0 seem to be solved in previous projects as Industry 4.0. Only data security seems to retain its role as an important challenge to be tackled in the context of Society 5.0.

The growth of primary studies in 2022 with respect to 2018 shows that the interest of the scientific community in Society 5.0 is constantly growing. Based on this, we expect to see a growing trend for both the sets of software engineering technologies and related challenges in the context of Society 5.0. Despite the number of scientific publications on Industry 4.0 is significantly larger than the number of publications on Society 5.0, it already seems that Society 5.0 is characterised by different relations with software engineering than Industry 4.0. In fact, it is worth remarking that 5 of the 13 software engineering technologies reported as significant for Society 5.0 are unique and not used in Industry 4.0 applications. Similarly, the most prominent technological challenge for Society 5.0, data security, pertains to Society 5.0, only. Eventually, several concerns regarding Society 5.0 are inherently related to ethical aspects. Hence, we expect to see a growing trend for research on ethical aspects on the use software engineering for Society 5.0.

V. Related Work

The concept of a sustainable smart society, also known as Society 5.0, introduced by the Japanese Council for Science, Technology and Innovation in 2016, has gained momentum in recent years. While it is still a relatively new area of research, several studies have shed light on specific aspects of Society 5.0. In this section, we review some of these works that either focus on the relationship between Society 5.0 and software engineering or are systematic studies of Society 5.0.

Rojas et al. proposed an infrastructure for realising Society 5.0 that involves the use of cyber and physical spaces with software engineering technologies [22]. Their systematic review covers the concept and social consequences of Society 5.0.In contrast to Rojas et al., our work employs a comprehensive research method that includes all available publications on a specific subject, rather than only surveying newly published literature. We focus on the role of software engineering technologies in realising Society 5.0, without focusing on specific areas of application. Frederico provided insight into the role of supply chains in Society 5.0 [22]. His results can be used by researchers and practitioners alike to understand the role of supply chains in Industry 5.0 and its benefits. While the focus of Frederico's work is on the supply chain domain, our work has a broader scope and does not focus on a specific domain. Peraković et al. conducted a systematic literature review on the role of AI in specific domains within Society 5.0, such as digital transport systems, healthcare, and manufacturing. In contrast, our work focuses on the role of software engineering technologies in realising Society 5.0, rather than just AI, without focusing on specific areas of application [23]. Peraković et al. also described key aspects of Industry 4.0 and Industry 5.0 environments and identified some pivotal software engineering technologies for realising Society 5.0. Our work provides a more thorough analysis of the extracted data employing both qualitative and quantitative analysis techniques [24]. Tornjanski et al. suggested research directions for strengthening the long-term well-being and prosperity of organizations, economies, and societies in Society 5.0 [25]. While their work is focused on organizational reinforcement, our work focuses on understanding the relationships between software engineering and Society 5.0. Nair et al. identified enabling technologies for Industry 4.0 and discussed the connection between Society 5.0 and management components [26]. Our work aims at surveying software engineering technologies and solutions enabling Society 5.0, and we used the results from their study to propose a comparison between Industry 4.0 and Society 5.0. Finally, Ghosh et al. proposed an AI-based Communication-as-a-Service solution for the communication framework of Society 5.0 [27]. While their work focuses on ACUTE, our study aims to survey software engineering technologies and solutions enabling Society 5.0, with ACUTE representing an example of such solutions.

VI. Conclusion and future work

Our systematic mapping study reveals that software engineering technologies are critical enablers in achieving Society 5.0. We identified 13 such technologies and ten challenges that hinder the realisation of Society 5.0. We also found that Society 5.0 has unique software engineering technologies and challenges not present in related projects like Industry 4.0. Therefore, future research should focus on understanding the role of these unique technologies and challenges. Additionally, ethical aspects of software engineering for Society 5.0 require further exploration.

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Primary studies

[p1] D. K. Jain, Y. Li, M. J. Er, Q. Xin, D. Gupta, and K. Shankar, "Enabling unmanned aerial vehicle borne secure communication with classification framework for industry 5.0," *IEEE Transactions on Industrial Informatics*, 2021.

[p2] X. Chen, M. A. Eder, A. Shihavuddin, and D. Zheng, "A human-cyber-physical system toward intelligent wind turbine operation and maintenance," *Sustainability*, vol. 13, no. 2, p. 561, 2021.

[p3] E. G. Carayannis, K. Christodoulou, P. Christodoulou, S. A. Chatzichristofis, and Z. Zinonos, "Known unknowns in an era of technological and viral disruptions—implications for theory, policy, and practice," *Journal of the knowledge economy*, pp. 1–24, 2021.

[p4] X. Xu, Y. Lu, B. Vogel-Heuser, and L. Wang, "Industry 4.0 and industry 5.0—inception, conception and perception," *Journal of Manufacturing Systems*, vol. 61, pp. 530–535, 2021.

[p5] S. Gaiardelli, S. Spellini, M. Lora, and F. Fummi, "Modeling in industry 5.0: What is there and what is missing: Special session 1: Languages for industry 5.0," in *2021 Forum on specification & Design Languages (FDL)*. IEEE, 2021, pp. 01–08.

[p6] V. Özdemir and N. Hekim, "Birth of industry 5.0: Making sense of big data with artificial intelligence,"the internet of things" and next-generation technology policy," *Omics: a journal of integrative biology*, vol. 22, no. 1, pp. 65–76, 2018.

[p7] S. M. Salaken, S. Nahavandi, C. McGinn, M. Hossny, K. Kelly, A. Abobakr, D. Nahavandi, and J. Iskander, "Development of a cloud-based computational framework for an empathetic robot," in *Proceedings of the 2019 11th International Conference on Computer and Automation Engineering*, 2019, pp. 102–108.

[p8] T. Sawaragi, Y. Horiguchi, and T. Hirose, "Design of productive socio-technical systems by human-system co-creation for super-smart society," *IFAC-PapersOnLine*, 2020.

[p9] E. Schoitsch, "Towards a resilient society - technology 5.0, risks and ethics," *IDIMT 2020: Digitalized Economy, Society and Information Management - 28th Interdisciplinary Information Management Talks*, 2020.

[p10] S. Shahzadi, M. Iqbal, and N. R. Chaudhry, "6g vision: Toward future collaborative cognitive communication (3c) systems," *IEEE Communications Standards Magazine*, vol. 5, no. 2, pp. 60–67, 2021.

[p11] M. Tabaa, F. Monteiro, H. Bensag, and A. Dandache, "Green industrial internet of things from a smart industry perspectives," *Energy Reports*, vol. 6, pp. 430–446, 2020.

[p12] D. K. Singh and R. Sobti, "Long-range real-time monitoring strategy for precision irrigation in urban and rural farming in society 5.0," *Computers & Industrial Engineering*, vol. 167, p. 107997, 2022.

[p13] T. Ghosh, A. Roy, and S. Misra, "B2h: Enabling delay-tolerant blockchain network in healthcare for society 5.0," *Computer Networks*, p. 108860, 2022.

[p14] T. Ghosh, R. Saha, A. Roy, I. Member, I. Sudip Misra, Senior Member, and N. S. Raghuwanshi, "Ai-based communication-as-a-service for network management in society 5.0," 2021. [Online]. Available: https://ieeexplore.ieee.org/document/9569743

[p15] A. Du, Y. Shen, Q. Zhang, L. Tseng, and M. Aloqaily, "Cracau: Byzantine machine learning meets industrial edge computing in industry 5.0," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 8, pp. 5435–5445, 2021.

[p16] A. Rajendran, P. M. Kebria, N. Mohajer, A. Khosravi, and S. Nahavandi, "A home for principal component analysis (pca) as part of a multi-agent safety system (mass) for human-robot collaboration (hrc) within the industry 5.0 enterprise architecture (ea)," in *2022 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, 2022, pp. 2569–2574.

[p17] H. Yang, A. Asheralieva, J. Zhang, M. M. Karim, D. Niyato, and K. A. Raza, "User-centric blockchain for industry 5.0 applications," in *2022 IEEE International Conference on Communications Workshops (ICC Workshops)*. IEEE, 2022, pp. 25–30.

[p18] T. Ghosh, A. Roy, and S. Misra, "I2m: Intelligent information management for rendering ioe services in society 5.0," *IEEE Transactions on Network Science and Engineering*, vol. 9, no. 5, pp. 2955–2965, 2022.

[p19] P. Mishra, P. Thakur, and G. Singh, "Sustainable smart city to society 5.0: State-of-the-art and research challenges," *SAIEE Africa Research Journal*, vol. 113, no. 4, pp. 152–164, 2022.

[p20] F. Gosselin, S. Kchir, G. Acher, F. Keith, O. Lebec, C. Louison, B. Luvison, F. M. de Chamisso, B. Meden, M. Morelli *et al.*, "Robot companion, an intelligent interactive robot coworker for the industry 5.0," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022, pp. 8918–8925.

[p21] M. Li, J. Gao, C. Zhou, X. Shen, and W. Zhuang, "Adaptive mobile vr content delivery for industrial 5.0," in *Proceedings of the 1st Workshop on Digital Twin & Edge AI for Industrial IoT*, 2022, pp. 1–6.

[p22] R. Sharma and R. Arya, "Uav based long range environment monitoring system with industry 5.0 perspectives for smart city infrastructure," *Computers & Industrial Engineering*, vol. 168, p. 108066, 2022.

[p23] F. Khan, R. L. Kumar, M. H. Abidi, S. Kadry, H. Alkhalefah, and M. K. Aboudaif, "Federated split learning model for industry 5.0: A data poisoning defense for edge computing," *Electronics*, vol. 11, no. 15, p. 2393, 2022.

[p24] X. Yao, N. Ma, J. Zhang, K. Wang, E. Yang, and M. Faccio, "Enhancing wisdom manufacturing as industrial metaverse for industry and society 5.0," *Journal of Intelligent Manufacturing*, pp. 1–21, 2022.

[p25] M. Ahmed, J. Liu, M. A. Mirza, W. U. Khan, and F. N. Al-Wesabi, "Marl based resource allocation scheme leveraging vehicular cloudlet in automotive-industry 5.0," *Journal of King Saud University-Computer and Information Sciences*, 2022.

[p26] J. Leng, W. Sha, B. Wang, P. Zheng, C. Zhuang, Q. Liu, T. Wuest, D. Mourtzis, and L. Wang, "Industry 5.0: Prospect and retrospect," *Journal of Manufacturing Systems*, vol. 65, pp. 279–295, 2022.

[p27] N. J. Rowan, "The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain–quo vadis?" *Aquaculture and Fisheries*, 2022.

[p28] P. Pant, A. S. Rajawat, S. Goyal, D. Singh, N. B. Constantin, M. S. Raboaca, and C. Verma, "Using machine learning for industry 5.0 efficiency prediction based on security and proposing models to enhance efficiency," in *2022 11th International Conference on System Modeling & Advancement in Research Trends (SMART)*. IEEE, 2022, pp. 909–914.

[p29] S. K. Jagatheesaperumal and M. Rahouti, "Building digital twins of cyber physical systems with metaverse for industry 5.0 and beyond," *IT Professional*, vol. 24, no. 6, pp. 34–40, 2022.

References

[1] Japanese Cabinet Office. About CSTI. Accessed November 19, 2021. [Online]. Available: https://www8.cao.go.jp/cstp/english/policy/index.html

[2] G. o. J. Cabinet Office. Society 5.0. Accessed December 13, 2021. [Online]. Available: https://www8.cao.go.jp/cstp/english/society5_0/index.html

[3] i scoop. Industry 4.0 and the fourth industrial revolution explained. Accessed December 19, 2021. [Online]. Available: https://www.i-scoop.eu/industry-4-0/#:~:text=Industry%204.0%20has%20been%20defined,and%20creating%20the%20smart%20factory%E2%80%9D.

[4] C. M. Valdor. Society 5.0. Accessed May 16, 2022. [Online]. Available: https://christianmanrique.com/2019/02/14/industry-4-0-and-society-5-0-by-christian-manrique/

[5] K. Petersen, R. Feldt, S. Mujtaba, and M. Mattsson, "Systematic mapping studies in software engineering," in *12th International Conference on Evaluation and Assessment in Software Engineering*, 2008.

[6] N. B. Ali and K. Petersen, "Evaluating strategies for study selection in systematic literature studies," in *Proceedings of the 8th ACM/IEEE international symposium on empirical software engineering and measurement*, 2014, pp. 1–4.

[7] C. Wohlin, "Guidelines for snowballing in systematic literature studies and a replication in software engineering," in *Proceedings of the 18th international conference on evaluation and assessment in software engineering*, 2014, pp. 1–10.

[8] V. R. B. G. Caldiera and H. D. Rombach, "The goal question metric approach," *Encyclopedia of software engineering*, pp. 528–532, 1994.

[9] B. Kitchenham and P. Brereton, "A systematic review of systematic review process research in software engineering," *Information and software technology*, vol. 55, no. 12, pp. 2049–2075, 2013.

[10] D. S. Cruzes and T. Dyba, "Recommended steps for thematic synthesis in software engineering," in *2011 international symposium on empirical software engineering and measurement*. IEEE, 2011, pp. 275–284.

[11] R. Franzosi, *Quantitative narrative analysis*. Sage, 2010, no. 162.

[12] M. Rodgers, A. Sowden, M. Petticrew, L. Arai, H. Roberts, N. Britten, and J. Popay, "Testing methodological guidance on the conduct of narrative synthesis in systematic reviews: effectiveness of interventions to promote smoke alarm ownership and function," *Evaluation*, vol. 15, no. 1, pp. 49–73, 2009.

[13] C. Wohlin, P. Runeson, M. Höst, M. C. Ohlsson, B. Regnell, and A. Wesslén, *Experimentation in software engineering*. Springer Science & Business Media, 2012.

[14] F. Haider. Countries with the largest aging population in the world. [Online]. Available: https://www.worldatlas.com/articles/countries-with-the-largest-aging-population-in-the-world.html

[15] i scoop. From industry 4.0 to society 5.0: the big societal transformation plan of japan. Accessed May 1, 2021. [Online]. Available: https://www.i-scoop.eu/industry-4-0/society-5-0/

[16] E. Ferko, A. Bucaioni, and M. Behnam, "Architecting digital twins," *IEEE Access*, vol. 10, pp. 50 335–50 350, 2022.

[17] A. Martinelli, A. Mina, and M. Moggi, "The enabling technologies of industry 4.0: examining the seeds of the fourth industrial revolution," *Industrial and Corporate Change*, vol. 30, no. 1, pp. 161–188, 2021.

[18] T. Zheng, M. Ardolino, A. Bacchetti, and M. Perona, "The applications of industry 4.0 technologies in manufacturing context: a systematic literature review," *International Journal of Production Research*, vol. 59, no. 6, pp. 1922–1954, 2021.

[19] P. K. R. Maddikunta, Q.-V. Pham, B. Prabadevi, N. Deepa, K. Dev, T. R. Gadekallu, R. Ruby, and M. Liyanage, "Industry 5.0: A survey on enabling technologies and potential applications," *Journal of Industrial Information Integration*, vol. 26, p. 100257, 2022.

[20] K. Zhou, T. Liu, and L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges," in *2015 12th International conference on fuzzy systems and knowledge discovery (FSKD)*. IEEE, 2015, pp. 2147–2152.

[21] E. Ferko, A. Bucaioni, M. Behnam, and P. Pelliccione, "Analysing interoperability in digital twin software architectures for manufacturing," in *17th European Conference on Software Architecture*, September 2023. [Online]. Available: http://www.ipr.mdu.se/publications/6720-

[22] C. N. Rojas, G. A. A. Peñafiel, D. F. L. Buitrago, and C. A. T. Romero, "Society 5.0: A japanese concept for a superintelligent society," 2021. [Online]. Available: https://www.researchgate.net/publication/352260300_Society_50_A_Japanese_Concept_for_a_Superintelligent_Society

[23] D. Perakovič, M. Periša, I. Cvitić, and P. Zorić, "Artificial intelligence application in different scenarios of the networked society 5.0 environment," 2021. [Online]. Available: https://www.sciencegate.app/document/10.37528/ftte/9788673954455/postel.2021.021

[24] ——, "Information and communication technologies for the society 5.0 environment," 2020. [Online]. Available: https://www.researchgate.net/publication/346571218_INFORMATION_AND_COMMUNICATION_TECHNOLOGIES_FOR_THE_SOCIETY_50_ENVIRONMENT

[25] V. Tornjanski and M. Čudanov, "Towards society 5.0 era: Organisational empowerment of the sustainable future," 2021.

[26] M. M. Nair, A. K. Tyagi, and N. Sreenath, "The future with industry 4.0 at the core of society 5.0: Open issues, future opportunities and challenges," 2021. [Online]. Available: https://ieeexplore.ieee.org/document/9402498

[27] T. Ghosh, R. Saha, A. Roy, I. Member, I. Sudip Misra, Senior Member, and N. S. Raghuwanshi, "Ai-based communication-as-a-service for network management in society 5.0," 2021. [Online]. Available: https://ieeexplore.ieee.org/document/9569743