Digital Transformation, Sustainability and Construction 5.0

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Abstract -
The United Nations has set the 2030 Agenda for Sustainable Development for the society, the environment and the economy with the 17 Sustainable Development Goals (SDGs). Countries act in collaborative partnership to take transformative steps to shift industries and society onto a sustainable and resilient path. Among all, digital transformation is one key domain of transformation to achieve sustainability. In the architecture, engineering, construction and operations (AECO) sector, the industry is slowly adopting digital transformation to different extents such as the use of Building Information Modelling (BIM), Internet of Things (IoT), computational tools, as well as automation in design and construction. Despite the commonly known practices and benefits of digital transformation such as productivity increase, the impacts of such transformation on sustainability have not yet been fully examined in research. The industry entails the corresponding digital transformation practices and their relationships with sustainability, so as to consider appropriate strategies. This work first investigates how the current practice in AECO adopts digital transformation, with case studies of the Japanese industry as examples; this is followed by the study of the relationships between digital transformation practices and the SDGs based on existing literature. Hence, the strategy propositions to assist the industry in current practice are elaborated. The research contributes to science by taking an initial step to examine the relationships between digital transformation and sustainability and present ready-to-adopt strategy propositions. Future research includes in-depth validations of the strategies and comparisons of the approaches in Japan with other countries.

Keywords -
Digital Transformation; Sustainability; SDGs; Construction 5.0

1 Introduction

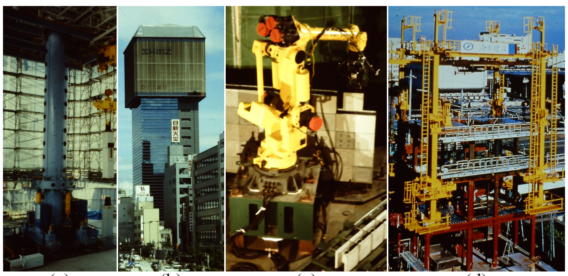
1.1 Sustainability and Digital Transformation

The 2030 Agenda for Sustainable Development set by the United Nations for the three dimensions of sustainable development - society (people), the environment (planet) and the economy (prosperity) - for all countries and stakeholders to implement this plan and take transformative steps in collaborative partnership. The goals are to transform the industries and society and balance the three dimensions. In regards to the society, the concept of sustainability comprises human well-being and a healthy environment; regarding the environment, sustainability is related to sustainable consumption, production and management in response to climate change and the needs of the present and future generations; in regards to the economy, sustainability supports the economic, social and technological progress of the nature and ecosystems [1]. Furthermore, in the context of sustainability in organizations, industries, and society, Elkington [2] presents the concept of the Triple Bottom Line, which comprises the environmental bottom line, the economic bottom line and the social bottom line.

The United Nations proposes the 17 Sustainable Development Goals (SDGs) for countries to achieve sustainability in societies and industries, including the architecture, engineering, construction and operations (AECO) sector, and ensure the implementation of the 2030 Agenda. United Nations [1] defines the 17 SDGs and actions by 2030 as follows: SDG 1 ensures the mobilization of resources to end poverty in multiple ways; SGD 2 safeguards food security and sustainable food production to increase productivity and maintain ecosystems; SDG 3 strengthens healthiness and well-being with affordable access to healthcare; SDG 4 ensures inclusive quality education and access to technology for education; SDG 5 enhances gender equality through policy adoption and technologies; SDG 6 reduces pollution and maintains water-related ecosystems; SDG 7 ensures infrastructure for access to clean energy research and technology; SDG 8 promotes productive employment and a safe working environment; SDG 9 enhances industrialization and fosters innovation through technological capabilities; SDG 10 reduces inequality via regulation; SDG 11 ensures inclusive cities, housing, transport systems and urbanization, as well as the protection of cultural and natural heritage; SDG 12 ensures sustainable consumption, production and management of natural resources with innovation; SDG 13 strengthens resilience and adaptive capacity to climate-related hazards; SDG 14 conserves oceans, seas and marine resources; SDG 15 restores sustainable use of terrestrial and inland ecosystems, manages forests and land degradation; SDG 16 promotes inclusive societies and participatory decision-making; SDG 17 revitalizes the partnership in finance, technology and capability-building.

The World in 2050 [3] consolidates six key domains of transformation for countries to provide pathways to achieve the 17 SDGs in ways that can be managed, in correspondence to appropriate infrastructure such as governance, values and policy tools. They are *human capacity and demography*, *consumption and production*, *decarbonization and energy*, *food, biosphere and water*, *smart cities* and *digital transformation*. Digital transformation can be defined as an "inter-connected set of discoveries and inventions" [3], as well as a form of business-model innovation or operational advancement through digitally-enabled provisions [4]. It involves emerging technologies such as robotics, artificial intelligence (AI), computer vision and remote sensing smart systems. It reshapes work, education and governance, as well as the production processes in every sector of the economy including the AECO sector. It can benefit productivity, accessibility, cost-effectiveness and material consumption to different extents. It could reduce lower-skilled jobs, incur inequality and bring challenges such as cybersecurity concerns, threats to the privacy of identities, digitally stored information, as well as social media manipulation etc. Moreover, digital transformation practices comprise *people*, *technology* and *process* to different extents [4, 5]. In general, it entails comprehensive governance to ensure that its impacts on our society can lead to sustainability for the next generation. Governance of technologies, AI and autonomous technical systems should align with the directions of the human-centered society so as to comprehend the potential benefits, liabilities and risks of the practices while avoiding the many potential downsides [3, 6]. Scholars such as Sachs et al. [7] and Vinuesa et al. [8] conducted literature reviews to study the relationships between digital transformation and each SDG and how the adoption of AI enables and inhibits each SDG respectively.

1.2 Digital Transformation in AECO



(a) (b) (c) (d)

Figure 1. Robot-Oriented Design (ROD) first applications in Japan: ROD SMART Juroku Ginko in Nagoya in (a) 1992 and (b) 1993; (c) ROD SMART proto Shimizu Research Institute (SRI) in 1988; (d) ROD SMAS Building Research Institute (BRI) MOC in 1985-1988.

The AECO sector in the construction industry is one of the world's least digitized among others with fragmented design and construction processes and supply chains. The fragmentation provides little incentive to embrace systemic innovation for developing new methods and digital tools and implementing new inventions. In AECO, the success of a transformation can be influenced by how technologies enable new ways of working, new products and services, as well as operational models to different extents [4]. State-of-the-art digitally-enabled provisions on projects include the implementation of Building Information Modelling (BIM), computational design, digital fabrication technologies including robotics and additive manufacturing such as 3D printing, as well as BIM-based and computer vision construction site monitoring, construction process digital twins and management etc [9]. Also, reality gaming technology realizes modular construction and digital twins of robotic construction respectively [10, 11]. BIM in design and construction enables the exchange of project information at the right time to make the right decision to facilitate environmental sustainability considerations during a building design process [12]. On the process level, digital transformation adopts digitally-enabled industrialized construction methods such as Robot-Oriented Design (ROD) [13]. The notion of ROD enables immediate availability by rapid assembly, high accuracy by robotic precision motion planning and positioning to adjust and fix the workpieces, adaptability by robotic deconstruction, repair and upgrading, reconstruction, reassembly and reconfiguration. This thus achieves closed-loop construction for the highest sustainability by robotic reuse of any building, construction component or processes. Figure 1 shows the first applications of ROD in Japan. The Solid Material Assembly System (SMAS) verified this approach between 1984 and 1988 at the Building Research Institute (BRI) in Tsukuba. In 1988 the ROD concept was tested at the prototype set up of the SMART system at the Shimizu Research Institute (SRI) in Etchujima, Koto Ku and Tokyo. The research was first published in Japanese in 1988 by the first author of [13] with the analysis of the first 50 construction robots built by the Japanese general contractors from 1978 to 1988. ROD has been implemented at the first SMART site of the Juroku Ginko in Nagoya for a 20-storied office building in 1992/3 and various high-rise projects until 2019. Moreover, a BIM-based process enables integrated processes and the adoption of emerging technologies in organizations and fosters innovation in technology [14]. In addition, digital transformation is emerging on the urban scale in the built environment. Scholars such as Biljecki and Ito [15] and Ruhlandt et al. [16] study computer vision applications for Geographic Information Systems (GIS) research blockchain-enabled smart city governance respectively.

1.3 Society 5.0 and Construction 5.0

In Japan, the government promotes the national vision - Society 5.0 - to link science, technology and innovation efforts to SDGs and revolutionize social problems to achieve SDGs using AI and automation technologies. Society 5.0 comprises a "human-centered system that integrates cyberspace and physical spaces. [...] It is envisioned as a successor of transformations" [17]. It includes the transdisciplinary concepts of digitalization, integration and sustainability [5]. The Society 5.0 initiative in Japan requires interdisciplinary studies on multiple scales to comprehend and analyse the policy and legal opportunities of adopting AI and automation [6]. The overarching research can be included in the context of *Construction 5.0*, which comprises digitalization, integration and sustainability based on recent scholarship that studies new approaches of digital transformation in construction [18, 19].

1.4 Research Objectives and Research Methods

Despite the potential contributions of digital transformation to sustainability in the industry in AECO, it has not yet been fully researched how it can be implemented to foster sustainability. In Japan, the industry has been adopting digital technologies to different extents in AECO. Through implementing the appropriate digital transformation practices, stakeholders can achieve sustainability for society, environment and economy through processes, technologies and people to different extents. From an overarching perspective, digital transformation practices can help the industry to achieve the 17 SDGs and realize Construction 5.0. More in-depth research is needed to examine the corresponding digital transformation practices and their relationships with sustainability, as well as the potential strategy proposition. This work aims to answer the research question as follows: *What digital transformation practices are related to sustainability in AECO?* To answer the question, the following research objectives are addressed: (RO1) to investigate how the current practice in AECO adopts digital transformation; (RO2) to investigate relationships between digital transformation practices and the SDGs; (RO3) to elaborate on potential strategy propositions to assist the industry in current practice, so as to realize Construction 5.0.

To address RO1, this work identifies the appropriate digital transformation practices with examples from case studies in the Japanese AECO. The first author collected the data of the case studies through reviews of authority documents [20], firms' documents, presentations and websites, as well as semi-structured interviews with firms' digital transformation teams. The data have been cross-referenced, summarised and consolidated in this work. To address RO2, this work maps the identified digital transformation practices with the corresponding 17 SDGs respectively through a summary and review of existing literature presented in Sachs et al. [7] and Vinuesa et al. [8]. The results have been firstly presented in Ng [19]. Based on the findings from case studies and existing literature, the strategy propositions are presented in the discussion section to address RO3. The research contributes to the body of knowledge in the fields of automation in construction, sustainability, design, construction and operation management, as well as technology governance by taking an initial step to examine the relationships between digital transformation and sustainability and elaborate on ready-to-adopt strategy propositions.

This work is structured as follows. Section 1 presents the backgrounds of the research as the points of departure, the key research question, three research objectives and the research methods. Section 2 includes the research findings of the identified digital transformation practices in AECO with examples from the Japanese industry, as well as the relationship between digital transformation and sustainability, namely SDGs respectively. Section 3 discusses the strategy proposition as recommendations for stakeholders to adopt digital transformation in current practice. Section 4 concludes the work and proposes future research directions.

2 Research Findings

2.1 Digital Transformation Practices in AECO

Based on a thorough summary of existing research review from The World in 2050 [3], [20], [8] and [7], 27 digital transformation practices are identified as shown in Table 1. Under the categories of *people*, *technology* and *process*, how AECO can adopt these practices in current practice through case studies of the Japanese industry is further studied. The initial results can be found in the report Ng [19].

DXP1 - Invest in digital technologies and infrastructure can impact the economy through technology. It can influence microeconomics within a firm and/or macroeconomics for a country to invest in scientific institutions. Many companies have been investing in state-of-the-art technologies such as digital twin interactive platforms to improve process and building performances during design, construction and operations stages. For example, digital twin platforms investment (DXP1) facilitates DXP7 during the construction process, and DXP13 through information integration. Also, BIM-based digital twins can support DXP6 such as the use of blockchain and smart contracts. *DXP2 - Promote collaboration and joint task development* can improve society through people development. This practice can involve collaboration among institutions, companies and public-private partnerships. On

Table 1. The identified 27 digital transformation practices in AECO under the major categories of *people (Pe)*, *technology (Te)* and *process (Pr)*, as well as *economy (Ec)*, *society (So)* and *environment (En)*. [19].

No.	Digital Transformation Practice	Category 1	Category 2
DXP1	Invest in digital technologies and infrastructure	Te	Ec
DXP2	Promote collaboration and joint task development	Pe	So
DXP3	Conduct predictions to make better plans of action	Te	Ec, En
DXP4	Optimize resources in design and planning	Pr	Ec, En
DXP5	Foster policy development for more efficient actions	Pr	Ec, So
DXP6	Support affordable and trusted documentation	Te	Ec, So
DXP7	Thorough waste management	Te, Pr	En
DXP8	Design for human health and social well-being	Pe	En
DXP9	Adopt digital analytical tools to improve performances	Te	Ec
DXP10	Enable cloud-based reality environment for training purposes	Pe, Te	So
DXP11	Optimize environmental and heritage values of local communities	Pe	Ec, So, En
DXP12	Automate decision-making	Pr	Ec
DXP13	Optimize resources in consumption through data monitoring	Te	En
DXP14	Extend accessibility and improve revenue	Pr	Ec
DXP15	Facilitate R&D to foster innovation and adoption of technology	Te	Ec
DXP16	Scale creativity and innovation	Te	Ec
DXP17	Increase the demand for jobs related to automation	Pe	Ec, So
DXP18	Enforce effective financial risk assessment	Pr	Ec
DXP19	Foster circularization and enable circular economy	Pr	Ec, En
DXP20	Optimize procurement process and supply-chain management	Pe, Pr	Ec, En
DXP21	Responsible sourcing of resources	Pr	En
DXP22	Improve financial transparency and simplify transaction process	Pr	Ec
DXP23	Enhance public and stakeholders engagements	Pe	So
DXP24	Develop specific digital tools to support sustainable practices	Te	En
DXP25	Optimize organizational structure	Pe	So
DXP26	Customize design tools and processes to optimize values	Te, Pr	En
DXP27	Provide cost-effective solutions	Pr	Ec

one hand, companies can collaborate with universities, institutions and organisations to jointly work on cutting-edge research and development; on the other hand, universities and educational institutes can collaborate with industry partners to promote industry-oriented educational activities or curricula to help educate the next-generation AECO professionals. *DXP3 - Conduct predictions to make better plans of action* can benefit the economy and the environment through technological development. This practice includes climate change forecasts using urban and geographic information such as urban building fabrics. In Japan, BIM-based simulation platforms are used to create virtual reality models to conduct predictions for assisting stakeholders to make better plans in design and construction. Also, a steel contractor uses customized computational tools can help to simulate robotic welding processes in 3D modelling and visualization for process prediction and real-time monitoring. *DXP4 - Optimize resources in design and planning* contributes to the economy and the environment through process development. This practice includes the optimization of design and resilience of infrastructure, buildings and construction, as well as the promotion of resource efficiency and the use of renewable materials based on informed decision-making already in the early design phase. In current practice, BIM-based digital platforms facilitate data integration and multi-disciplinary collaboration from the design phase to the building operation phase. When used correctly, BIM-based design processes and management can foster other practices such as DXP7 and DXP9, as well as DXP6, DXP12 and DXP13 to assist management during the construction and operations phases. *DXP5 - Foster policy development for more efficient actions* can benefit the economy and society through process improvement. For example, the Japanese government has been initiating the Society 5.0 framework for efficient actions to achieve the 2030 Agenda and the SDGs in industries and society [17]. Collaboration between academics, industry practitioners and policy-makers (DXP2) can ensure appropriate policies and policy deployment that can deliver effective benefits to society. *DXP6 - Support affordable and trusted documentation* can impact the economy and society through technological development. This practice can assist stakeholders in construction process management and establish a common data environment with paperless recording to support trusted documentation. Also, BIM-based platforms also facilitate affordable and trusted real-time documentation among multi-parties on a project. *DXP7 - Thorough waste management* benefits the environment through technology and process development. In AECO; companies adopt this practice by assigning waste management specialists on projects to conduct evaluations of site wastes and waste disposal strategies. They monitor the proper collection of by-products generated on construction sites for recycling. Also, integrated BIM-based platforms can document material information and foster DX19. Moreover, the current practice has demonstrated that BIM-based design for manufacture and assembly (DfMA) processes reduce wastes at construction sites and save costs to different extents during the design and construction processes. *DXP8 - Design for human health and social well-being* supports the environment through the development of people. Some companies in Japan use digital systems, which are connected to a company's internal human resources systems, to detect and record the body temperature of workers with their masks and helmets on to enhance human health at construction sites during the pandemic period. *DXP9 - Adopt digital analytical tools to improve performances* improves the economy through technological development. The use of, for example, digital twin interactive systems help to improve performances in building design and construction in terms of efficiency and cost-effectiveness. This practice can foster other practices such as DX7 and DX13.

DXP10 - Enable cloud-based reality environment for training purposes can benefit society through people and technological developments. This practice can impact workforce development in society. In current practice, state-of-the-art digital twin platforms enable a cloud-based reality environment to help train complex fabrication processes. This not only enhances workers' capability, encourages the young generation to take part in the construction sector, but also assists pre-job site health and safety training. *DXP11 - Optimize environmental and heritage values of local communities* can impact the economy, society and environment through development about people. In Japan, contractors who specialize in cultural heritage retrofits using traditional fabrication methods such as prefabrication of carpentry work, state-of-the-art industrialized construction methods and computational design tools to optimize the heritage values of the historic built environment. Built heritage, which possesses historical values and cultural significance including but not limited to embodied historical craftsmanship and construction knowledge, enhances the cohesion of the local communities. *DXP12 - Automate decision-making* supports the economy through process development. In the current practice in Japan, contractors and sub-contractors invent their bespoke customized digital tools to facilitate simulations, building information analyses and visualization and other practices such as DXP9 and DXP26. This can automate decision-making to optimize design and construction processes. *DXP13 - Optimize resources in consumption through data monitoring* can benefit the environment through technological development. State-of-the-art digital twins platforms enable consumption-aware processes through real-time monitoring. This also facilitates DXP7 during construction and operations. Data monitoring can be further foster other practices such as DXP6 and DXP19. *DXP14 - Extend accessibility and improve revenue* can impact the economy through process development. It is commonly acknowledged in the industry that digital transformation can increase productivity and accessibility, and reduce production costs and material consumption [3]. Recent research such as Grüter et al. [21] shows how to scale up the competitiveness of circular construction through the use of digital building design optimization tools, reflecting a link between DXP13, DXP14 and DXP19. Also, recent scholarship studies the actor-network study of how digital design and digital fabrication can be implemented to potentially general profits in the current industry through a systemic literature review [22]. Both *DXP15 - Facilitate research and development (R&D) to foster innovation and adoption of technology* and *DXP16 - Scale creativity and innovation* can benefit the economy through the development of technology. This practice can be implemented with other practices such as DXP2 to promote collaboration and joint task development and spur innovation among organizations in the industry. *DXP17 - Increase the demand for jobs related to automation* facilitates the development of the economy and society through developing people-related aspects and workforce. In Japan, trade contractors have been adopting automated design tools and digitized life-cycle management systems to automate value chains from design and planning to fabrication phases. They increase the job opportunities for high-skilled professionals to facilitate automation processes. *DXP18 - Enforce effective financial risk assessment* can impact the economy through process development. In Japan, customized electronic commerce services have been currently used in practice for users to order, receive and make payments by scanning QR codes displayed on a terminal. Digital services can help to improve financial transparency simplify transaction processes and enforce effective financial risk assessment for procurement.

DXP19 - Foster circularization and enable circular economy can impact on the economy and the environment through process development. In AECO, this practice promotes a circular economic model of reuse and recycling of existing resources. In current practice, for example, Japanese house-makers use BIM-based integrated systems for pre-design planning, design, construction, operations and maintenance and end-of-life management to manage resources throughout the building life cycle and facilitate material circularization. This practice not only saves materials and costs but also enables design to reduce the amount of building components for ease of disassembly and reassembly. *DXP20 - Optimize procurement process and supply-chain management* can benefit the economy and the environment through people and process developments. A Japanese house-maker has been transforming their "Scrap and Build" approach to a "Stock-type Society" approach by constructing houses with a longer lifespan. With appropriate design approaches for manufacture and assembly, as well as design approaches for disassembly, BIM-based platforms can help to facilitate DfMA to consider constructability during the early design phase and optimize the procurement process and supply chain management. *DXP21 - Responsible sourcing of resources* supports the environment through process development. In current practice, for example, a Japanese general contractor uses locally sourced cedar timber materials to fabricate cross-laminated timber (CLT) load-bearing walls and floors with digital fabrication technology through information integration in BIM. *DXP22 - Improve financial transparency and simplify transaction process* can benefit the economy through process development. A Japanese general contractor has been using a construction site co-creation platform, which provides electronic commerce services with financial transparency, This can simplify the transaction process and reduce financial risk for procurement to different extents. Also, a Japanese house-maker uses blockchain technology to ensure the security of trusted information exchange and financial transparency and simplify the transaction process with an effective end-to-end solution for services ranging from the real estate lease agreement process to establishing insurance contracts. *DXP23 - Enhance public and stakeholders engagements* and *DXP25 - Optimize organizational structure* can impact on the society through development about people. State-of-the-art mixed reality technologies have been implemented to assist design-to-construction processes for off-site progress inspection remotely in an interactive and immersive reality environment. This can enhance stakeholders' engagement for design review and discussion during the early design phase. The Japanese house-makers optimize organizational structure with vertical integration and advance training to promote responsible procurement and co-creation for sustainable development through partnership and collaborative work. *DXP24 - Develop specific digital tools to support sustainable practices* supports the environment through technological development. On existing projects, building information analysis, simulation and visualization using state-of-the-art analytical computational design tools to optimize building performance such as energy consumption, daylight intake etc. during the early design phase. *DXP26 - Customize design tools and processes to optimize values* can impact the environment through process and technological developments. Customized tools can improve, for example, carbon emission during digital fabrication processes by precise calculation and design of structural and non-structural parts of the building components. *DXP27 - Provide cost-effective solutions* can benefit the economy through process development. For example, a Japanese supplier uses commercial BIM platforms for DfMA with QR-coded packaging to assist logistics, fabrication and on-site assembly process and reduce wastes on site (DXP7).

2.2 Digital Transformation Practices for 17 SDGs

Figure 2 shows the categorizations of the 27 digital transformation practices and the mapping of the uni-directional relationships from each of the 27 practices to the 17 SDGs to different extents through a summary of the literature review work mainly from [3], Sachs et al. [7], Vinuesa et al. [8] and other industry reports. The diagram and the work have been initially presented in Ng [19].

Among all, DXP3 and DXP4 can achieve ten SDGs. DXP3 can achieve, for example, SDG 13.1 target - Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters; DXP4 can address several targets such as SDG 9.1 target - Develop quality, reliable, sustainable and resilient infrastructure to support economic development and human well-being. Also, the practice can achieve SDG 8.4 target - Improve progressively. This facilitates global resource efficiency in consumption and production and endeavours to decouple economic growth from environmental degradation. Also, DXP13 can achieve eight SDGs; DXP1 and DXP7 are found to achieve seven and six SDGs respectively. Besides, it is identified that SDG 11 - Sustainable cities and communities and SDG 12 - Responsible consumption and production can be enabled by 11 practices. For example, DXP15 can achieve SDG 11; SDG 12 can also be enabled through DXP19; SDG 8 - Decent work and economic growth and SDG 9 - Industry, innovation and infrastructure can be enabled by eight practices. They can be enabled by, for example, DXP11. Also, SDG 17 - Partnership for the Goals can be enabled by seven practices including DXP23.

3 Discussion

This work presents an initial study of digital transformation and the corresponding impacts on sustainability in AECO. In current practice, existing adoptions of digitalization in planning, design, construction, operations and maintenance, as well as management, can foster sustainable development to different extents on project scale, building scale, urban scale, in the built environment and beyond the AECO sector. Construction 5.0 includes digitalization, integration and sustainability. It leads to a high-level concept of environmental, societal and economic advancements in industries and society, such as the Society 5.0 concept in Japan. Based on the research, five potential strategy propositions in Construction 5.0 are presented as follows. They can be implemented immediately by stakeholders on projects, organizational reforms and in the built environment. Also, they can lead to potential future research directions, which include a systemic literature review, in-depth investigations and case-based validation of the digital transformation practices and the relationships with SDGs.

- All-rounded solutions that integrate digital technologies development, organizational, information and process integration, as well as sustainability, are needed to shape Construction 5.0.

- Joint collaborations between research and practical implementation can be conducted on projects in the forms of, for example, integrated digital project delivery business models, early contractor involvement in concurrent engineering, as well as rewards sharing mechanisms.

- State-of-the-art BIM-based approaches for sustainability, including resource circularization and circular economy business models, process and cost predictions for better estimations and optimizations in processes and building performances can be promoted.

- Process-based transition management in the AECO sector holds the potential for combined achievements in the key areas of a resource-efficient and decarbonized built environment.

- Appropriate business models are required in practice to invest and facilitate R&D, scale creativity and turn inventions into innovations, enforce effective financial risk assessments, extend accessibility of technologies, as well as provide cost-effective solutions.

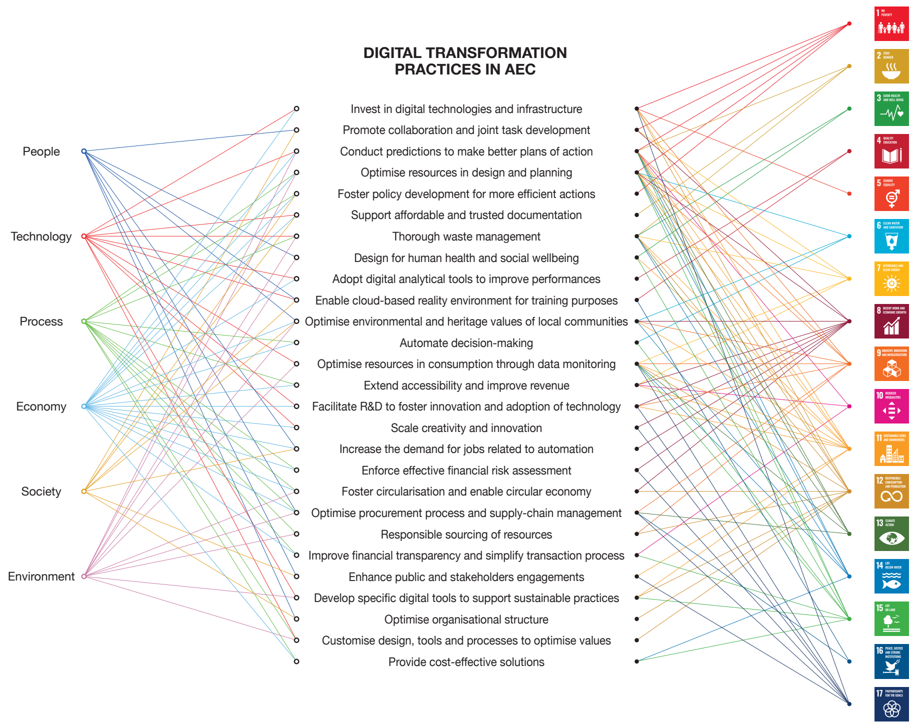


Figure 2. A tripartite diagram presenting the digital transformation practices in the AECO sector for achieving the 17 SDGs under the holistic improvement framework of people, process and technology - and the three pillars of sustainability - economy, society and environment [19]. Data are based on The World in 2050 [3] and Vinuesa et al. [8]. SDG color courtesy of UN/SDG.

4 Conclusion

This work investigates digital transformation to achieve sustainability and the 2030 Agenda for Sustainable Development for society, the environment and the economy. To assist the industry in adopting digitalization in current practice, 27 digital transformation practices are identified. They include *DXP4 - Optimize resources in design and planning* and *DXP19 - Foster circularization and enable circular economy* that foster the economy and the environment, *DXP6 - Support affordable and trusted documentation* and *DXP17 - Increase the demand for jobs related to automation* that foster the economy and society, *DX23 - Enhance public and stakeholders engagements* that benefit the society, as well as *DXP26 - Customize design tools and processes to optimize values* to improve the environment. All practices are supported with the case studies of the Japanese industry to show how the current practice has been adopting digitalization to different extents and demonstrate the feasibility. For example, Japanese house-makers use BIM-based integrated systems to manage resources throughout the building life cycle to facilitate DXP19. Moreover, the relationships of how the 27 practices can foster the 17 SDGs respectively are investigated. The results show that DXP3 and DXP4 can achieve ten SDGs including SDG 13.1 target - Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters. Also, SDG 11 - Sustainable cities and communities and SDG 12 - Responsible consumption and production can be enabled by 11 practices such as DX19 and *DXP21 - Responsible sourcing of resources*. Moreover, five strategy propositions in Construction 5.0 as future research directions that can be further investigated and validated are presented. They include process-based transition management for combined achievements to enable a resource-efficient and decarbonized built environment. This research presents an initial study of connecting tangible digital transformation practices that have been adopted in Japan as examples and explores novel research directions, which can be continued by scientists and practitioners to establish comprehensive concepts of Construction 5.0 for the coming ten years approaching 2030 and beyond. Also, the work aims to assist stakeholders in taking action in correspondence to the 2030 Agenda, achieving SDGs and realizing Society 5.0 through technological advancements to solve societal, environmental and economic challenges through appropriate strategies for process, technologiical and people.related developments. Future research includes in-depth quantitative and qualitative validations of the strategies and thorough comparative studies of Japan's approaches with other countries for broader insights.

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