ACHIEVING SUSTAINABILITY THROUGH THE CIRCULAR ECONOMY IN THE SPACE SECTOR

Chekfoung Tan
UCL Centre for Systems Engineering, University College London, chekfoung.tan@ucl.ac.uk, 3 Taviton Street, London, WC1H 0BT, UK.

Michael Emes
UCL Centre for Systems Engineering, University College London, m.emes@ucl.ac.uk, 3 Taviton Street, London, WC1H 0BT, UK.

Muna M. Alhammad
College of Business Administration, King Saud University, malhammad@ksu.edu.sa, Riyadh 11451, Saudi Arabia.

Abstract

Inspired by Industry 4.0, the Space 4.0 terminology is coined to reflect the new era where technologies have enabled more actors from the commercial sector or developing nations to participate in the value chain. This phenomenon has also prompted sustainability issues such as the vast amount of space debris orbiting Earth. Circular economy could offer a solution for the sustainability issue. However, the existing information system (IS) research shows limited work in integrating Industry 4.0 and circular economy in achieving sustainability, including the space sector. Therefore, this developmental paper aims to fill this gap by first studying the relevant concepts followed by illustrating the next phase of this research using case studies. This research intends to contribute to achieving sustainability by circular economy driven by Industry 4.0 in the space sector, which will be pivotal in expanding the domain knowledge of IS research.

Keywords: Industry 4.0, Circular Economy, Sustainability, Space Sector, Information Systems Research

1.0 Introduction

The space industry is a high technology environment. Hence, the efficient use of digital technologies is vital for ensuring the success of space operations, particularly in a sustainable way from the social, economic and environmental perspectives. The space industry has entered so-called Space 4.0, a new space era that leads to increasing numbers of space actors, ranging from governments to commercialised organisations, and elevates space activities (Bohlmann & Petrovici, 2019). Some sustainability issues, such as environmental impact, have recently attracted attention. According to the UK Space Agency (2022), orbital congestion created by space debris, which could stay in orbit for hundreds of years, is an increasingly challenging issue facing the space industry. There are approximately 330 million pieces of space debris, with 36,500 objects bigger than 10 cm (e.g., old satellites, spent rocket bodies, and tools dropped by astronauts) orbiting Earth.

The concept of a 'Circular economy' (CE), reflected by the 6Rs (Reduce, Reuse, Recycle, Recover, Remanufacture and Redesign) posited by Khan et al. (2021), is one way to address the sustainability issue. There is existing work within the information systems (IS) realm in studying how industry 4.0 contributes to sustainable development such as Müller and Buliga (2019) and Bordeleau et al. (2021). However, research integrating Industry 4.0, sustainability, and circular economy is still in its infancy in general, including the space sector (adapted from Paladini et al., 2021).

Space 4.0 is a concept built on Industry 4.0 (Aloini et al., 2021). Therefore, this developmental paper explores how Industry 4.0 integrates with the concept of circular economy, which eventually leads to achieving sustainability through preliminary literature analysis. This paper first covers the application of Industry 4.0 in the space sector that drives Space 4.0, followed by integrating the circular economy concept in the space sector. This paper then presents a conceptual map suggesting the ontological relationship of the three main themes (Industry 4.0, circular economy and sustainability) and suggest the subsequent few phases of this research. This research intends to contribute to achieving sustainability by circular economy driven by Industry 4.0 in the space sector, which will be pivotal in expanding the domain knowledge of IS research.

2.0 Related Work

2.1 Implications of Industry 4.0 in driving Space 4.0

Industry 4.0 is seen as the fourth generation of the industrial revolution. The first and second generation of the industrial revolution was enabled by steam, water and electricity power, and the third industrial revolution refers to the application of IT systems for automating production further. With the advancement of sensors, network and data analytics technologies, the concept of Industry 4.0, sometimes referred to as the Industrial Internet of Things, has emerged. It refers to the cyber-physical systems where physical and virtual worlds are merged (Müller & Buliga, 2019). The Industry 4.0 concept was first coined at the Hannover Fair in 2011 refers to the manufacturing competitiveness by the German government (Lasi et al., 2014). There are nine technologies under the umbrella of Industry 4.0 (Rüßmann et al., 2015), as demonstrated in Table 1.

Space 4.0 marks a new era of space activities (Bohlmann & Petrovici, 2019). Looking back in the past, Space 1.0 started when astronomers first discovered the celestial bodies in outer space. Space 2.0 saw a political rivalry for national security purposes and a space race during the Cold War, from Sputnik to the Apollo era. Space 3.0 fostered international cooperation efforts, and one of the flagship projects was the International Space Station (ISS). The project was jointly invested by Europe, the USA, Canada, Russia and Japan. As in Space 4.0, driven by Industry 4.0, it enables more actors from the smaller nations to participate in space activities. For instance, Industry 4.0 contributes to small satellite development, which provides cheaper access to space for developing nations. Space 4.0 revolutionises space activities from state-driven to privatisation and commercialisation and enhances the collaboration between government and private sectors. In addition, Space 4.0 changes the space manufacturing landscape and leads to information exchange for developing new partnerships with space actors to foster sustainable development on Earth and outer space (Böning, 2021; EuropeanSpaceAgency, 2018). More importantly, Industry 4.0 improves resource efficiency hence contributing to sustainable value creation from the social, economic and environmental perspectives (Sharma et al., 2020). Table 1 illustrates the example applications of Industry 4.0 in the space sector.

Industry 4.0 Technology	Examples of applications in the space sector	Sources
Big data analytics	Apply large volume of satellite data contributes to agriculture, climate change and defence research. Optimise space mission Increase efficiency of satellite management Perform space surveillance and tracking to support the removal of orbital debris	(Keppel & Bretagnolle, 2018; UKSpaceAgency, 2022)
Autonomous robots	Perform in-orbit assembly	(Roa Garzon et al., 2017)
Simulation	Enable 3D simulations of products, materials and production processes in the space sector by leveraging real-time data which mirrors the physical world in a virtual model.	(adapted from Rüßmann et al., 2015)
Horizontal and vertical system integration	Integrate IT systems better across departments, functions, and capabilities within an organisation, which will impact space systems or related operations	(Aloini et al., 2021)
Internet of things	Enhance manufacturing and decision making process through the use of sensors and analytics, for instance, in the satellite manufacturing and operation Inspire new business models in the space industry	(Aloini et al., 2021; Braun & Braun, 2020)
Cybersecurity	Ensure secure and reliable communications. For instance, vulnerabilities in the software and hardware used in the satellite could impact the satellite's operation and robustness of security controls.	(Aloini et al., 2021; Manulis et al., 2021)
Cloud computing	Utilise cloud functionality such as vast processing power or storage space. For instance, huge amount of geospatial data were made available in the cloud and by integrating with other data sources for creating new services and value propositions	(Aloini et al., 2021; Duke, 2019)
Additive manufacturing	Offer construction advantages, such as complex, lightweight designs, by producing small batches of customised products. For instance, 3D printing was applied in the International Space Station for producing space tools, or equipment astronauts might need onboard	(Cao, 2020; Rüßmann et al., 2015)
Augmented reality	Facilitate new visualisation of space vehicle designs and analysis	(Cipriano & Biesbroek, 2018)

Table 1. Example applications of Industry 4.0 in the space sector

2.2 Circular Economy in the Space Sector

Circular economy is an emerging trend that aims to use natural resources in a sustainable manner (McDowall et al., 2017). Instead of a linear model of *"take, make, use and dispose"*, it applies the model of (Jabbour et al., 2020). According to EllenMacArthurFoundation (2022), the three principles of circular economy are driven by design: 1) eliminate waste and pollution, 2) circulate products and materials (at their highest value), and 3) regenerate nature. Ultimately, it drives towards an efficient use of finite resources. The circular economy principles are initially driven by industrial processes and waste management (Paladini et al., 2021). CE is impacting the business model of organisations, particularly the value chain.

The space sector has a long value-added chain (OECD, 2007). It starts with the upstream segment, which includes research and development actors and space hardware manufacturers such as launch vehicles, satellites and ground stations. The chain ends with space-enabled products providers such as navigation equipment and satellite phones and services to end-users such as satellite-based meteorological services or direct-to-home video services, which refers to the downstream segment.

Commercial space sectors such as companies like Space X from the founder of Tesla, Elon Musk, Blue Origin founded by Amazon CEO Jeff Bezos, and the Spaceship Company founded by Richard Branson embrace the circular economy concept (Brennan & Vecchi, 2020). They tend to keep the resources in use as long as possible while extracting the maximum value, then recovering and regenerating their materials at the end of each service life. Particularly with the concept of reusability, Space X claims that it will help reduce the launch cost from $61 million to $5-7 million. For instance, Space X pioneers the technology of returning expended rocket stages to Earth by landing them back on dedicated pads or oceangoing barges for later reuse. This approach helps in driving the costs down further.

Apart from the economic benefits, the circular economy encourages new ventures, driving technological and business model innovations. According to Brennan and Vecchi (2020), experiential learning, resilience, entrepreneurial mindset, and effective leadership potentially contribute to the success of applying circular economy in the space sector.

3.0 Research Approach

This paper adopts a preliminary literature analysis method to produce a conceptual map (see Figure 1) of integrating the three main research themes: Industry 4.0, circular economy, and sustainability. Based on the thematic ontology as in Tan et al. (2015), the conceptual map demonstrates the ontological relationship of themes, which sets the foundation for future work. The main themes at this stage are extracted based on heuristics following Gregory and Muntermann (2014).

4.0 Preliminary Findings

The nine technological advancements in Industry 4.0 contribute to digitalisation. According to Khan et al. (2021), it is impacting sustainable development from the triple bottom line (social, economic and environmental sustainability)(Elkington, 1998), sustainable business model and circular economy perspectives. Circular economy blends well in the concept of sustainable manufacturing, where it is facilitated by big data analytics and cooperation among the value network actors (Bordeleau et al., 2021). The application of current technological advancements in Industry 4.0 should not be confined to building sustainable manufacturing but also to leveraging existing or new technical systems that enable the creation of sustainable knowledge within the space industry. Sustainable knowledge seeks to add value while reducing waste. By applying circular economy, knowledge and data can be reprocessed to produce new knowledge to minimise waste. Additionally, the capabilities of companies of commercial space sectors in knowledge coordination, development, and distribution can facilitate the application of circular economy and hence, in building a sustainable space industry.

There is existing IS literature discussing the application of Industry 4.0 in various sectors, but it is rather limited in the space industry. Looking at the non-IS literature, most of the Industry 4.0 applications in the space industry mainly focus on the product or component level. Similarly, there is still a lack of integration of how circular economy applies industry 4.0 for sustainability purposes in the space sector. The space sector could be worth up to US$ 720 billion by 2030, and circular economy could contribute to US$ 340 to 380 billion of annual material cost savings (Paladini et al., 2021). According to the United Nations Economics and Social Council (2020), space technologies have contributed to accelerating sustainable development. For example, a cloud-based crop monitoring technology, Crop Watch Cloud, enables countries to conduct independent crop monitoring and early warning related to food security without investing in the establishment and operational costs. Furthermore, circular economy impacts an organisation's business model, regardless of whether they are in the market player in the upstream or downstream segment. Therefore, there are opportunities for IS scholars to explore further the application of Industry 4.0, particularly in the value chain of the space sector, from the organisational perspective, which is the main contribution of this paper at the present state. Figure 1 illustrates the conceptual map of the preliminary literature findings.

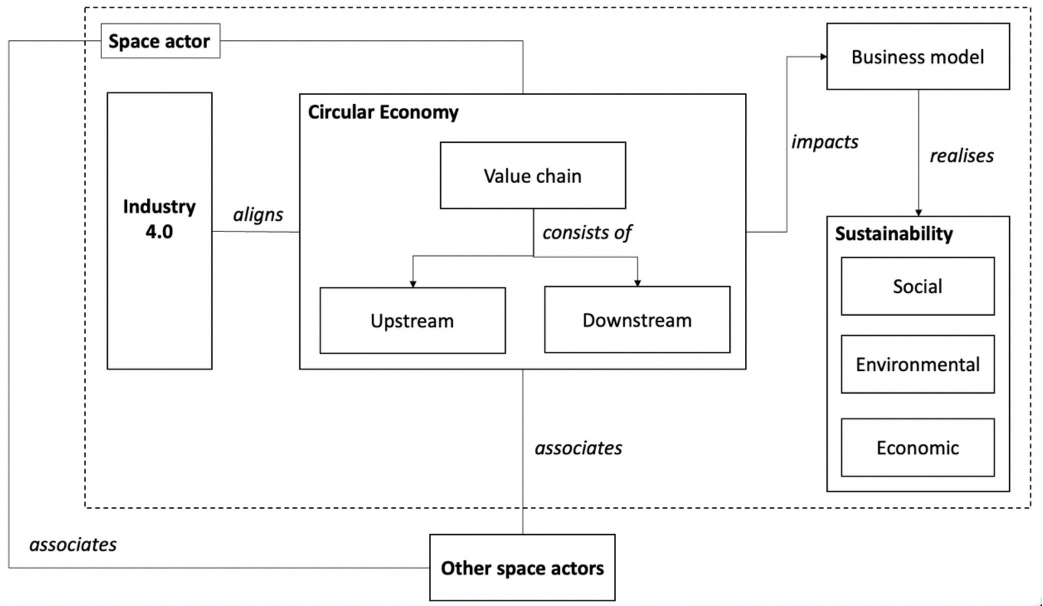

Figure 1. Achieving Sustainability through Circular Economy driven by Industry 4.0 in the Space Sector

The space actor refers to a space organisation involved in the value chain, which could be part of the upstream or downstream segment. This chain could potentially involve other space actors or space organisations.

5.0 Future Work

The next stage of this research will involve a systematic literature review following the stages demonstrated in Alhammad et al. (2022). The results will further expand the themes and sub-themes as in Figure 1. Case study research following Yin (2018) will be conducted where space organisations involved in space operations will be selected for investigating the level of adoption of Industry 4.0, aligning with the 6Rs (Reduce, Reuse, Recycle, Recover, Remanufacture and Redesign) (Khan et al., 2021) in the value chain. This investigation will also cover how IS sustainability solutions such as creating sustainable knowledge can contribute to producing a sustainable space sector. The data collected will then inform how circular economy impacts the business model, hence achieving the sustainability purpose.

References

Alhammad, M. M., Tan, C., Alsarhani, N., & Zolkepli, I. A. (2022). What Impacts Backers' Behavior to Fund Reward-Based Crowdfunding Projects? A Systematic Review Study. *Pacific Asia Journal of the Association for Information Systems*, *14*(2), 7.

Aloini, D., Latronico, L., & Pellegrini, L. (2021). The impact of digital technologies on business models. Insights from the space industry. *Measuring Business Excellence*.

Bohlmann, U. M., & Petrovici, G. (2019). Developing planetary sustainability: Legal challenges of Space 4.0. *Global Sustainability*, *2*.

Böning, S. (2021). The Current State of Research and Technology of Digitalization in the Space Industry.

Bordeleau, F.-È., Santa-Eulalia, L. A., & Mosconi, E. (2021). Digital Transformation Framework: Creating Sensing, Smart, Sustainable and Social (S^ 4) Organisations.

Braun, B. M., & Braun, M. (2020). Space and the Internet of Things. 2020 IEEE Aerospace Conference,

Brennan, L., & Vecchi, A. (2020). The orbital circular economy framework: Emblematic evidence from the space industry. *Kindai Management Review*, *8*(1), 81-92.

Cao, S. (2020). *How 3D Printing in Space Will Help Put a Million People on Mars*. Retrieved 06 February 2022 from https://observer.com/2020/10/3d-printing-international-space-station-made-in-space-interview/

Cipriano, A., & Biesbroek, R. (2018). A survey of Augmented Reality use in the Concurrent Design Facility. *Proc. 'SECESA*, *18*.

Duke, C. S., Greg; Herr, Daniel. (2019). *Industry 4.0 and the Future of UK Space Manufacturing*.

Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environmental quality management*, *8*(1), 37-51.

EllenMacArthurFoundation. (2022). *What is a circular economy?* Retrieved 31 December 2021 from https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

EuropeanSpaceAgency. (2018). *A toolbox for sustainability*. Retrieved 06 February 2022 from https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/Space_for_Sustainable_Development/A_toolbox_for_sustainability

Gregory, R. W., & Muntermann, J. (2014). Heuristic Theorizing: Proactively Generating Design Theories. *Information Systems Research*, *25*(3), 639-653.

Jabbour, C. J. C., Fiorini, P. D. C., Ndubisi, N. O., Queiroz, M. M., & Piato, É. L. (2020). Digitally-enabled sustainable supply chains in the 21st century: A review and a research agenda. *Science of the total environment*, *725*, 138177.

Keppel, D., & Bretagnolle, P. (2018). An Empirical Exploration of the Potential Benefits of Applying Big Data Analytics for Improved Space to Space Operations Management in the Satellite Industry. *Chaire-sirius. eu*.

Khan, I. S., Ahmad, M. O., & Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. *Journal of Cleaner Production*, *297*, 126655.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239-242.

Manulis, M., Bridges, C. P., Harrison, R., Sekar, V., & Davis, A. (2021). Cyber security in new space. *International Journal of Information Security*, *20*(3), 287-311.

McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., Kemp, R., & Doménech, T. (2017). Circular economy policies in China and Europe. *Journal of Industrial Ecology*, *21*(3), 651-661.

Müller, J., & Buliga, O. (2019). Archetypes for data-driven business models for manufacturing companies in industry 4.0.

OECD. (2007). Executive Summary and introduction. In *The Space Economy at a Glance 2007*. OECD Publishing.

Paladini, S., Saha, K., & Pierron, X. (2021). Sustainable space for a sustainable earth? Circular economy insights from the space sector. *Journal of Environmental Management*, *289*, 112511.

Roa Garzon, M. A., Nottensteiner, K., Wedler, A., & Grunwald, G. (2017). Robotic technologies for in-space assembly operations. 14th Symposium on Advanced Space Technologies in Robotics and Automation (ASTRA),

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston consulting group*, *9*(1), 54-89.

Sharma, R., Jabbour, C. J. C., & de Sousa Jabbour, A. B. L. (2020). Sustainable manufacturing and industry 4.0: what we know and what we don't. *Journal of Enterprise Information Management*.

Tan, C., Sun, L., & Liu, K. (2015). Big Data Architecture for Pervasive Healthcare: A Literature Review. In *23rd European Conference on Information Systems (ECIS 2015)*. Münster, Germany.

UKSpaceAgency. (2022). *New funding to support sustainable future of space*. Retrieved 06 February 2022 from https://www.gov.uk/government/news/new-funding-to-support-sustainable-future-of-space

UnitedNationsEconomicsAndSocialCouncil. (2020). *Exploring space technologies for sustainable development and the benefits of international research collaboration in this context*.

Yin, R. K. (2018). *Case Study Research and Applications: Design and methods* (Vol. 6). Sage publications.