MANAGING SMART SYSTEMS FOR THE NET ZERO AGENDA – HOW CAN DIGITAL TWIN TECHNOLOGIES AND SMART PRODUCTS DELIVER CUSTOMER VALUE?

Markey, Charlotte Lucinda;
Ahmed-Kristensen, Saeema

University of Exeter

ABSTRACT

Using the case study of a smart green blue roof pilot project in Greater Manchester, the authors have coded and analysed a series of semi structured interviews. We present our findings which are specifically focused on how 'smart' was understood by the multiple stakeholders involved in the project and how product complexity is managed when digital technologies are integrated into nature based solutions that are becoming more popularised in the construction sector. This integration of digital twin and sensor technologies with physical drainage products to create the next generation of smart green blue infrastructure, presents numerous challenges for organisations in the construction sector. We conclude that the need for smart systems of systems in this sector necessitates organisational change and new methods of knowledge transfer across organisations who work together to deliver the holistic physical and digital services to the client.

Keywords: Digital Twin, Smart Systems and Products, Sustainability, Collaborative design, Complexity

Contact:
Markey, Charlotte Lucinda
University of Exeter
United Kingdom
charlotte.markey@polypipe.com

Cite this article: Markey, C. L., Ahmed-Kristensen, S. (2023) 'Managing Smart Systems for the Net Zero Agenda – How Can Digital Twin Technologies and Smart Products Deliver Customer Value?', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.255

1 DIGITAL TECHNOLOGY FOR SUSTAINABILITY AND NET ZERO - SMART PRODUCTS

The construction industry faces a plethora of challenges but is also afforded numerous opportunities; from the political, societal and economic drivers towards sustainability and the legislative framework that now requires the implementation of high quality green and blue infrastructure / nature-based solutions in the UK and beyond. Industry 4.0 offers digital technologies and optimisation to enable more sustainable, resource efficient construction projects and associated green blue infrastructure interventions. Manufacturers are increasingly integrating traditional products and services PSS (Product-Service Systems), with digital contents. Digital products and digitally-enabled services, for example, monitoring and real time diagnostics, are now included in a complete value proposition to the client. As Porter et al. (2014) argue, SCP (Smart Connected Products) and cloud-based technologies are key to this digital transformation. We describe a discrete case study of a smart blue green roof pilot in central Manchester to demonstrate the challenges and opportunities for organisations developing and commercialising SCP for built environment applications. The "Smart Roof System" consists of a physical drainage layer complete with sensors and a hub to provide real time analytics regarding the vitality of the soil and green asset, as well as a link to predictive weather analytics to ensure that the roof drains down before a storm event. This system is predicated on creating a DT (Digital Twin) of the roof and using AI to optimise the accuracy and performance of the remote valves used to control the drain down rates.

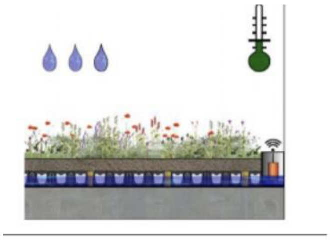

Figure 1. Typical green blue roof build up. Source: Voeten et al (2020)

This digital twin, which models outcomes in the event of weather fluctuations, metamorphoses the roof from a passive to an active feature. It is the development of, and connection, between the physical drainage and landscape solutions for the roof, the sensors, hub and software, (including the DT technologies) that forms the smart system and evolves the 'package' offered to the market from a series of discrete products into something which adds more value than the sum of its parts, a system. Maier (1999) puts forward a clear argument of what constitutes a system of systems: "System-of-systems, as commonly used, suggests assemblages of components that are themselves significantly complex, enough so that they may be regarded as systems and that are assembled into a larger system." Critically, for the purposes of the smart green blue roof, each component, both physical and digital - the drainage layer, substrate, sensors and hub that constitute the smart roof, are all by their nature, complex systems in their own right and it is their assemblage that creates the overarching smart roof.

2 STATE OF THE ART

We consider scholarship focused on the conception of 'smart', the use of digital twin technology and predictive analytics for green blue roof applications to create 'customer value'. We have chosen to focus on the concept of 'smart products' and how the definition has evolved. Raff et al. (2020) provides a clear overview: "extant research about smart products is based on increasingly unstable ground. Despite the popularity of smart products as a field of research, in many respects there is no real consensus or clarity about what a smart product actually is. Porter and Heppelmann (2015) define three core elements: physical components, 'smart' components, and connectivity components. This "smartness" is facilitated by Digital Twin technologies. (Garetti et al. 2012) have the following

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

definition for a Digital Twin: “The DT consists of a virtual representation of a production system that is able to run on different simulation disciplines that is characterized by the synchronization between the virtual and real system, thanks to sensed data and connected smart devices, mathematical models and real time data elaboration. The topical role within Industry 4.0 manufacturing systems is to exploit these features to forecast and optimize the behaviour of the production system at each life cycle phase in real time.” How then is this 'smart' element of these solutions linked to customer value? SCP and SS (Smart Systems), offer a series of new capabilities and opportunities to create value., According to Porter (2014), these capabilities enable four different goals: a) monitoring, b) controlling, c) optimizing, and d) being autonomous in performing some business tasks. Pynnonen et al. (2011) have observed that customer value can also be systemic and is often contingent on one or more attributes and can sometimes only be realised through the customer obtaining that value from one or more firm. This closely relates to the more general situation we see with the advent of 'industry 4.0' and 'construction 4.0' with manufacturing and tech firms working in collaboration to deliver multiple layers of value throughout a project lifecycle. West et al. (2020) noted that digital twins can assist organisations to create new value to customers through servitization. They also note that throughout each phase of the project life cycle they can interact with the wider smart product environment and add value. It is clear, as Lee et al. (2014) argue, data alone cannot add value, therefore, this research analyses how smart and value were conceptualised and how whether or not partners commercialising the product communicated the value of these SCP. Importantly, whether or not value was understood in the same way across stakeholder groups.

2.1 The concept of 'smart' as applied to green blue roof systems - integrating technology with nature based solutions

Voeten et al. (2022) delineate between no tech, low tech and high-tech approaches to nature-based solutions in urban environments, focused on green blue roofs and tree pits in hard landscaped environments. They explicitly link the concept of tech NBS, the use of sensor technologies akin to the roof case study we considered as the basis for this paper, with the "water smart city" and they provide a clear overview of the function and benefits of tech NBS: "High tech vegetated roofs and city trees are capable of capturing, storing and re-using precipitation, on-site. Their design incorporates an open, high-strength, geocellular structure underneath the soil, allowing for measurable supplemental water retention. The system provides a controllable retention capacity up to 140 mm and uses natural capillary irrigation to return water to the soil during droughts" water sensitive design and resource efficiency are at the core of the argument: "High tech vegetated roofs and city trees are at the core of harvesting rainwater not just for later plant irrigation but also for other functions …these functions can be realized from the start..." There are notable shortcomings of the model advanced by Voeten et al. (2022) and the decision-making toolkit they provide for stakeholders when considering the levels of technology, they wish to incorporate into their Nature Based Solutions.

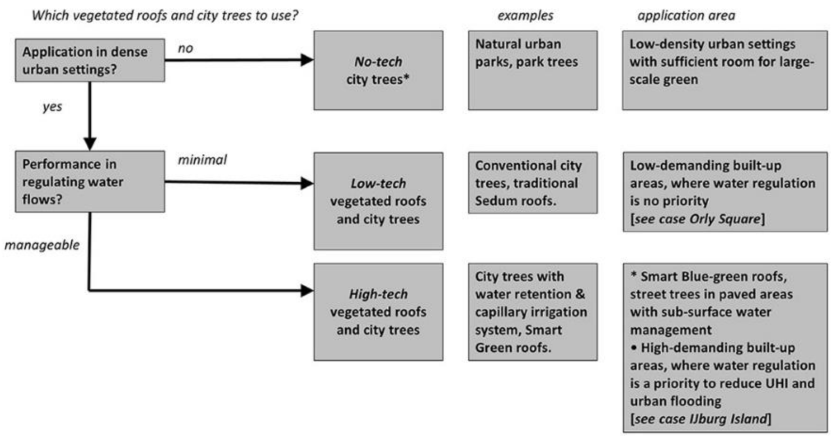

Figure 2. NBS model. Source: Voeten et al (2022)

The model considers a very narrow set of parameters and does not incorporate critical factors in the diffusion of new innovations. It does not help to explain how the 'tech' and 'smart' elements of these NBS are communicated to stakeholders and how customer value is conveyed. The value that can be

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

derived from 'smart' NBS must also be considered in relation to the project life cycle. Morris (2013) notes that the mutual adjustments and interactions between organisations within a networked system of stakeholders throughout the project lifecycle is key

2.2 Theoretical contribution to the diffusion and adoption of "Tech NBS"

This research builds upon extant models of diffusion and innovation to consider how trust and inter organisational knowledge exchange have an impact on the conception of "tech NBS" and their complexity and how these impact on the acceptance of such technologies. DOI (Diffusion of Innovation) theory, identified four elements of innovation: (1) the innovation itself, (2) communication channels, (3) time, and (4) social system. The DOI theory further identified five forces that influence the rate of innovation adoption (1) relative advantage (2) compatibility (3) complexity (4) trial ability (5) observability. During diffusion process these forces decrease uncertainty about the innovation. Other models such as the Technology Acceptance Model, TOE Model and Theory of Reasoned Action, have also tried to present comprehensive accounts of the factors that impact rates of technology acceptance:

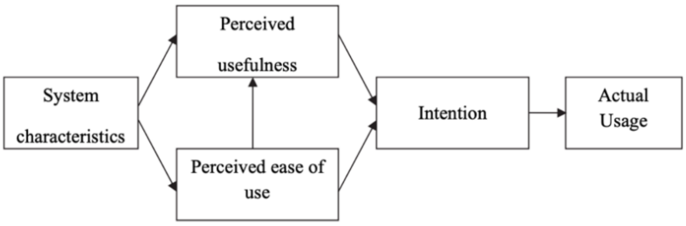

Figure 3. TAM Model. Source: Davis et al (1989)

These models are mostly derived from psychology, motivational theories and sociology, often focusing predominantly on the perspective of an individual 'end user' of a specific technology. Many have been extended over the years, for example by Venkatesh et al (2008), but they still do not take account of the nexus of relationships, the strong and weak ties between individuals, intra organisational networks and inter organisational networks which account for success or failure of new smart connected products across construction and related industries. The 'VTAM' model has been proposed which integrates customer values and technology adoption. Value is broken down into emotional, functional, social, and likeliness to adopt a balance of value satisfaction against technology barriers, price and risk. This conception of value becomes problematic when considered beyond the micro or meso level. To what extent do emotional and social values really impact an adoption decision when considered at a larger scale? These models require extensive modification and more detailed analysis of specific variables to make them applicable and meaningful in particular scenarios. It is the contention of this paper that there is a critical link between the strength of the inter organisation networks required to bring Tech NBS to market and organisational performance and this, in turn, has an impact on the acceptance and adoption of 'tech NBS'. With this in mind, it is then possible to provide strategic recommendations in order for organisations to achieve sustained competitive advantage and commercialise future iterations of these SCP for application into green and blue infrastructure projects. There is little research that provides a robust framework to facilitate "conveyance" of value from the project to the operational phases. It is also arguable that with the tech element of the NBS, new opportunities are opened up to add value particularly at the post installation and operational phases. Oftentimes value creation at the front end of a project is over looked due to the difficulties of incorporating metrics to capture success and areas for improvement at these early stages. However, this research builds on the work of Mantinheiki et al. (2016) who provide a framework for value creation at the front end:

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

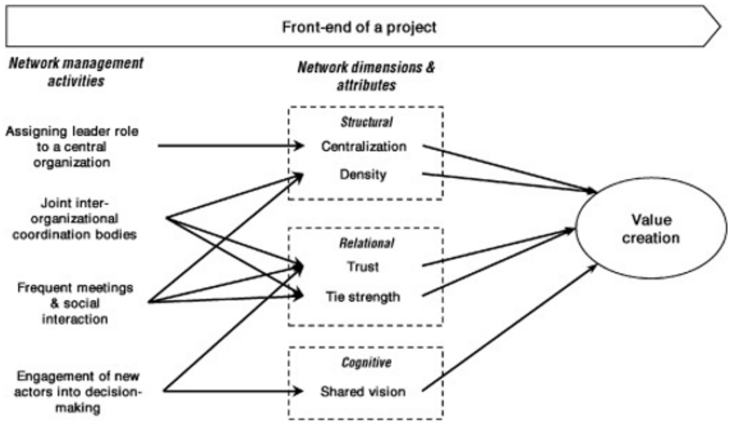

Figure 4. Source: Mantinheiki et al (2016)

This model provides a valuable framework from which to base an understanding of how the consortium analysed in this case study were able to commercialise the 'smart roof' system and communicate value.

It is our hypothesis that NBS is an emergent area where technologies are integrated and systems are increasing in their complexity. Therefore, it is more important that end users - specifiers, designers, and clients are engaged in the co creation of value. More successful co creation of value will make it more likely that these systems will be adopted across a broader spectrum of projects. This is closely related to the concept of 'service-dominant logic'. S-D logic, defined by Vargo and Lusch (2004), frames economic and social exchange in terms of service that creates value through customers' and firms' participation in the development process. It is therefore vital that the 'customer' understands the technology and its capabilities in order to engage in this co creation process. If the customer does not understand the architecture of the "tech NBS" system, it becomes problematic to foster a network of partners across the project to co create and add value and ultimately realise the full benefits of the system. We also contribute to the extant theories of technology acceptance through addressing the variable of complexity with a greater emphasis on customer value. Kim et al. (2019) have contended that there is a negative relationship between feature complexity and technology acceptance. We would refute this claim and argue that based on the semi structured interviews, there is a clear understanding amongst designers and clients that their required feature benefits and desired extensions to a basic system will deliver more value but require a series of more complex processes in order to achieve the preferred outcomes. This leads to the important questions as to the extent to which organisations must shoulder the 'complexity burden'

2.3 Research question and objectives

For the purposes of this paper, we explore the link between the use of smart products to support green sustainable drainage solutions and how value is conveyed to specifiers and designers. We investigate this through a case-study of a smart product to support a retrofit green blue roof. The following research question is addressed: How can organisations adjust their management of innovations and communications of complex products to assist the uptake of new smart systems throughout the project lifecycle and convey value?

3 METHODLOGY

A case study approach was adopted, with a series of twelve semi-structured interviews conducted with key stakeholders from the smart blue green roof project in Manchester. The use of semi-structured interviews enabled flexibility whilst also facilitating a consistency of questions. The stakeholders chosen were representative of key decision makers from the Consortium and External Stakeholders. The coding system was developed from a bottom-up approach to identify the interplay between the development of the 'smart system' together with the associated digital twin technology that supports it and the creation and communication of customer value. All of the interviews were segmented, and coded, and themes identified. In this paper, we focus on the connection between stakeholders' perception of the 'smart system' itself and the ability of this new service offer, piloted on the Manchester roof, to deliver value.

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

Table 1. Interviewee List

Stakeholder Type	Discipline / Job Role	Role In Project
Client (3 interviewees)	Three stakeholders interviewed from project management and sustainability departments	Project management, Sustainability
Designer/Specifier (2 Interviewees)	Landscape Architecture	Design of the landscape architecture supported by the smart systems and physical geocellular solutions
Project Partners (6 interviewees)	Green roof expert, sensor manufacturer, digital twin and forecasting partner, hydraulic modeller, manufacturer partner	Delivery of the smart products and physical solutions as a package
Expert consultant (1 interviewee)	Green Infrastructure consultant	This expert is independent and reviews roof projects for other independent organisations interested in advancing knowledge of green blue roofs

The interviewer, and one of the authors is an embedded researcher within one of the companies and thus was able to access key stakeholders across the project lifecycle. Interviewees were made explicitly aware of the interviewers' industry affiliations and their data has been anonymised for the purposes of the research. The interviews were semi-structured and aimed at answering the following questions:

For External Stakeholders (Clients, Specifiers, Consultant)

What do you understand by the concept of 'smart'?

What were your objectives in applying the smart roof system?

What are your perceived benefits of using this system compared to a basic green and blue roof package?

Did you understand at the beginning of the project what the system could accomplish and has that understanding changed as the project has progressed?

Where do you think value has most been added and can be added by 'smart' - Beginning/Middle/End of Project?

What did you know about how 'smart' might be integrated into a green blue roof system before the project compared to now the project has been delivered?

Were you able to work with the project team to create additional value and capture more benefits?

For Internal Stakeholders (Project Partners):

What is your position in your organisation and your involvement with the development of the smart roof system?

Could you describe how the organisations involved in development of the product worked together - were there improvements that could be made and how might you improve this?

Did you have all the information you needed to fulfil your elements of the project?

Who would you go to for advice and to achieve the strategic aims and objectives of the project?

Can you describe how the consortium have established specific working groups / ways of working to share knowledge and commercialise the system?

How was information shared between partners in order to fulfil client information requirements and fully design/install the project?

4 FINDINGS - CONCEPTUALISING THE 'VALUE' OF SMART PRODUCTS AND THE SMART ROOF CASE STUDY

In order to develop and commercialise smart connected products for application in the built environment sector, more traditional manufacturers who offer physical products are creating new

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

networks and establishing inter organisational partnerships with tech firms to realise the potential and add several layers of value to their initial offering. With this additional complexity of product, we asked the members of consortium how they perceived the value of 'smart' and how the value might be communicated to clients and specifiers. From an analysis of the interviewees from within the consortium, their perception of the value of the product could be broken down into the following parameters which formed the sub codes of value that were explored:

- Autonomy
- Integration with Existing BMS
- Optimisation
- Accuracy and Predictability
- Risk Management

The following challenges were identified across the consortium interviewees:

- Agreeing cost and the value of each partner's expertise
- Trust between partners
- Knowledge Management Processes
- Branding 'smart' and agreeing a strategic process of product launch and long-term promotion
- Individual networks and strengths/weaknesses of ties
- Lack of agility
- Lack of confidence in managing design changes and complexity as client and designer requirements evolve.
- Lack of agreed process for product management

When the Client was interviewed regarding the value that can be derived by 'smart', based on the coded interviews, it was clear that the CapEx element of the work was the least referenced form of value for the client and their appointed design teams. The most common forms of value captured were:

- Biodiversity and Biodiversity Net Gain
- Health and Well Being
- Placemaking and Amenity

These can all be considered aspects of ‘customer experience’ and it was clear that whilst the Client was mindful that additional amenity value from the retrofitted 'smart roof' could translate into potential uplift in city centre rental income, the smart connected products would add value to their ‘brand’ as pioneering stakeholders in the city with spaces that provided value to multiple stakeholders; end users of their workspaces, the utility companies and the local council. The ability to demonstrate asset performance and to show planners and key stakeholders how the system was providing water management, pollutant removal and biodiversity benefits enabled the client to broker conversations with planning authorities and to achieve the environmental credentials on their project that they aimed for. The second project they are looking to deliver in Leeds will excel the industry BREEAM ratings for the building with the use of the 'smart system'. The Client delivering the Manchester roof wanted to evolve the design for the Leeds project and link the 'smart roof' to a new 'smart' living wall in order to achieve additional environmental and water management benefits. The Client described the challenges at early design stage of the additional complexities that these design changes would entail. It was clear from interviewing both the client and those from the Consortium facilitating this added complexity burden that 'smart' as seen as a cure all, anything could be achieved or any feature optimised and that the added complexity was not an additional challenge to the Client. It was however, more problematic for the Consortium who did not have the inter organisational frameworks in place to rapidly respond. The response, although acceptable for this short-term pilot scheme, could not be normalised. When we asked the Client the extent to which they had been able to co create value and determine outcomes they noted the following opportunities and challenges:

- Delineating between the 'smart' and physical aspects of the system and where value could be added at which stages in the project lifecycle was not understood
- Understanding if value could be captured retrospectively and in which case whether new sensors and additional digital elements needed to be considered
- The opportunity of the 'smart roof' to be integrated with other systems but questions pertaining to the complexity of compatibility with other nature-based solution systems

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press

5 CONCLUSIONS AND FURTHER RESEARCH

Through these interviews several forms of value were explored from multiple perspectives. We have observed that the Client was willing to accept higher levels of complexity in order to achieve a greater range of value across the lifecycle of the project and to extend the capabilities of the 'smart' products for future developments. This finding calls into question previous research that has postulated that complexity will have adverse impacts on the creation of customer value and the willingness to adopt (Kim et al, 2019). The interviews highlighted that existing technology acceptance frameworks and theories could not easily be applied to technologies such as a smart roof where a physical technology (patented geocellular and passive irrigation technology in the case of the green blue roof) and the sensor and hub package that form the 'system' are combined. This presents a situation where two forms of technology are both dependent but are enhanced through synthesis. Therefore, ease of use and complexity as variables in extant models need to be adjusted to account for this. Smart Connected Products such as the smart roof require that the 'Systems Characteristic' aspect of TAM or extended models be extended to account for both the cyber and the physical. The concept of 'technological autonomy' was confirmed as a positive value by both the Client and the Consortium. The Client exhibited no mistrust in the technological autonomy associated with the roof draining down itself ahead of a storm. This challenges previous work, notably Constantinides et al. (2017) as there was no negative correlation in our interviews between autonomy and willingness to adopt. The Client and design community demonstrated a clear weighting toward the placemaking, and aesthetic value derived from the physical layer and the complexity of the installation was considered more than the 'smart' element. There was an assumption that this aspect would "be taken care of" as one Client interviewee noted.

Whilst Voeten's model provides a basic rationale for the types of projects for which additional technologies may be desirable, it is apparent that the design and diffusion of "tech NBS" requires a synthesis of theoretical frameworks to explain how knowledge exchange and trust can improve organisational performance. Social Network Analysis would provide a fruitful trajectory through which to explore how knowledge and complexity of Smart Connected Products can be better managed and organisational performance enhanced. As Chan and Leibowitz (2006) note, "A direct tie with the knowledge source(s) must be established and trust must be built (Krebs, 2003; Ford, 2003). Trust plays an important role in knowledge sharing, which is the most commonly discussed knowledge management process with respect to the synergy of social network analysis and knowledge mapping and trust" (Ford, 2003). Although inter organisational networks have been analysed from an SNA perspective and tie strengths and trust have been connected (Dyer and Nobeoka, 2000), we would build on Gulati et al. (2011), who utilise the concepts of Resources, Richness and Reach to assess networks. Not all organisations will exhibit the same ability to leverage resources across inter organisational boundaries and many models neglect the specificity and heterogeneity of organisations commercialising innovations across these boundaries. A model could be developed where the Richness, Reach and Resources of each organisation in a network were analysed to predict knowledge exchange capabilities and organisational performance to indicate the potential of successful diffusion of their new smart NBS innovations. Extant technology acceptance models need to be supplemented specifically with a better understanding of the complexity and features of the products in question. Further research should consider to what extent the 'complexity burden' can be managed through more effective communication between networks throughout the project lifecycle.

ACKNOWLEDGMENTS

We would like to acknowledge Polypipe, the industry sponsor of Charlotte Markey's PhD thesis and who provided access to case study data. We would also like to thank the interviewees including members of the Smart Roof joint venture who delivered the 'smart roof' project in Greater Manchester. This work was also supported by the Engineering and Physical Sciences Research Council (grant number EP/T022566/1). DIGIT Lab is a Next Stage Digital Economy Centre

REFERENCES

Bessant J. and Tidd, J. (2013) *Managing Innovation*, John Wiley, London.

Byballe, L. and Ingemansson, M. (2014) "The Logic of Innovation in Construction", *Industrial Marketing Management*, Vol 43 (3), pp.512-524. https://doi.org/10.1016/j.indmarman.2013.12.019

Constantinides, E., Kahlert, M., & de Vries, S. A. (2017). "The relevance of technological autonomy in the acceptance of IoT services in retail." Paper presented at 2nd International Conference on Internet of Things, Data and Cloud Computing, *ICC* 2017, Cambridge, United Kingdom. https://doi.org/10.1145/3018896.3018906

Davis,F.D. (1989) "*A Technology Acceptance Model for Empirically Testing New End-user information Systems: Theory and Results. Doctoral Dissertation*", MIT Sloan School of Management, Cambridge, MA. http://hdl.handle.net/1721.1/15192

Eckert, C. et al. (2008) "Exploration of Correlations between Factors Influencing Communication in Complex Product Development." *Concurrent Engineering*, Vol 16, pp.37-59. https://doi.org/10.1177/1063293X07084638

Dyer, J. and Nobeoka, K. (2000) "Creating and Managing a High-Performance Knowledge Sharing Network: The Toyota Case". *Strategic Management Journal*, Vol.21, pp. 345-367.http://dx.doi.org/10.1002/

Edmonson, A.C. et al. (2003) "Learning How and Learning What: Effects of Tacit Knowledge on Performance Improvement Following Technology Adoption, *Decision Sciences*, Vol. 34, pp 197-224. https://doi.org/10.1111/1540-5915.02316

Garetti, et al. (2012) "Sustainable manufacturing: trends and research challenges" *Prod. Plann. Contr.*, Vol.23, pp. 83-104. http:// 10.1080/09537287.2011.591619

Grieves and Vickers (2017) "Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems." In: Kahlen, J., Flumerfelt, S. and Alves, A., Eds., *Transdisciplinary Perspectives on Complex Systems*, *Springer*, Cham, pp.85-113. https://doi.org/10.1007/978-3-319-38756-7_4

Gulati, R. et al (2011) "How do networks matter? The performance effects of interorganizational networks", *Research in Organizational Behaviour, Vol.31, pp.207-224.* https://doi.org/10.1016/j.riob.2011.09.005

Kim, et al (2019)"Information Technology Acceptance in the Internal Audit Profession Impact of Technology Features and Complexity*", International Journal of Accounting Information Systems*, Vol. 10 (4), pp. 214-228. https://doi.org/10.1016/j.accinf.2009.09.001

Maier, M. (1999), "Architecting Principles for Systems of Systems", *Systems Engineering*, Vol.1. https://doi.org/10.1002/(SICI)1520-6858

Mantinheiki, et al (2016) "Managing Inter-Organizational Networks for Value Creation in the front-end of Projects", *International Journal of Project Management, Vol 34 (7), pp.1226*-1241 https://doi.org/10.1016/j.ijproman.2016.06.003

Paschou, T. et al (2020) "Digital Servitization in Manufacturing: A Categorical Literature Review and Classification". *IFAC*, Vol 51(11), pp.1016-1022. https://doi.org/10.1016/j.ifacol.2018.08.474

Payne, et al. (2017) "The Customer Value Proposition", *Journal of the Academy of Marketing Science*, Vol. 45, pp. 467–489. https://doi.org/10.1007/s11747-017-0523-z

Porter and Heppelmann (2015) "How Smart Connected Products are Transforming Competition", *Harvard Business Review.* https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition.

Pynnonen, et al. (2011) "The New Meaning of Customer Value: A Systemic Perspective*", Journal of Business Strategy*, Vol 32 (1), pp.51-57. https://doi.org/10.1108/02756661111100328.

Raff, et al. (2020), "Smart Products, Conceptual Review, Synthesis and Research Directions", *Journal of Product Innovation Management*, Vol. 37, pp 379-404. https://doi.org/10.1111/jpim.12544.

Rapaccini, M. and Adrodegari, F. (2022) "Conceptualising Customer Value in Data-Driven Services and Smart PPS" *Computers in Industry*, Vol 137. https://doi.org/10.1016/j.compind.2022.103607

Rijsdijk, S.A. and Hultink, E.J. (2009) "How Today's Consumers Perceive Tomorrow's Smart Products" *Journal of Product Innovation Management*, Vol 26, pp.24-42. https://doi.org/10.1111/j.1540-5885.2009.00332.x

Sharma, et al. (2020) Digital Twins: "State of the art theory and practice, challenges, and open research questions", *Journal of Industrial Information Integration*, Volume 30, https://doi.org/10.1016/j.jii.2022.100383

Vargo, S. L., & Lusch, R. F. (2004). "Evolving to a New Dominant Logic for Marketing". *Journal of Marketing*, Vol.68(1), pp.1–17. https://doi.org/10.1509/jmkg.68.1.1.24036

Ventkatesh.V, et al (2008) "Technology Acceptance Model 3 and a Research Agenda on Interventions", *Bus. Decis.Sci*, Vol.9 (2). https://10.1111/J.1540-5915.2008.00192.X

Voeten, et al. (2020) "Nature Based Solutions for Urban Resilience: A Distinction Between No Tech, Low Tech and High-Tech Solutions", *Frontiers in Environmental Sciences, Vol.8*. https://doi.org/10.3389/fenvs.2020.599060

West, et al. (2021) "Digital Twin Providing New Opportunities for Value Co-Creation through Supporting Decision Making", *Applied Sciences*, Vol 11. https://doi.org/10.3390/app11093750

Youn and Lee (2019)"Proposing Value-Based Technology Acceptance Model: Testing on Paid Mobile Media Service", *Fashion and Textiles*, Vol 6. https://doi.org/10.1186/s40691-018-0163-z

https://doi.org/10.1017/pds.2023.255 Published online by Cambridge University Press