Crafting an IoT-Ecosystem – A Three-Phased Approach

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Completed Research

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Abstract

The Internet of Things acts as a seed for enterprises to collaborate and create new value. This value creation is often concentrated in big enterprises that command large amounts of resources. The craft sector's small and medium sized enterprises struggle to adopt such new technologies. Lacking resources and in-house capabilities, they increasingly rely on services provided by large enterprises. Collaboration among equals can offer an alternative path for these small and medium sized enterprises. Combining their strengths in an IoT-ecosystem is one way to overcome these limitations. We conducted a case study in the electrical engineering craft to build such an IoT-ecosystem. Participating organizations planned how to develop the existing ecosystem into an IoT-ecosystem. This process was observed to be structured into a status quo and three sequential phases. Our research shows, that sharing data can act as the initial phase to unlock new value in an existing ecosystem. Every enterprise can then work on connecting its clients' systems to enable an eventual opening to join the IoT-ecosystem. This three-phased approach offers enterprises a tool to work towards an IoT-ecosystem. Researchers can apply the three-phased approach as an analytic tool to reason about progress towards an IoT-ecosystem.

Keywords

Internet of Things, craft sector, IoT-ecosystem, small and medium sized enterprise, SME.

Introduction

The Internet of Things (IoT) is beginning to change business processes (Friedow et al., 2018). An increasing number of things in our environment can be interacted with seamlessly, regardless of physical distance. They are often integrated into business processes to, for example, coordinate logistics (Prasse et al., 2014) unlocking new value for enterprises (Kiel et al., 2017). However, implementing an IoT solution can be challenging, especially for small and medium sized enterprises (SMEs) (Parker, 2020). Their specialization in to narrow niches allows them to effectively collaborate with other SMEs to develop new solutions (Koo and Lee, 2018). The IoT is a technology that has the potential to create new value within ecosystems (Weber et al., 2019) facilitating such SME collaboration. The lifecycle of platform ecosystems has been studied by researchers (Tiwana, 2014; Teece, 2017; Stummer et al., 2018; Jacobides et al., 2018) in the context of one company providing a platform and other ecosystem participants using it. Enterprises collaborating on equal terms through the IoT are departing from this notion. They create value by forming collaborative IoT-ecosystems (Leminen, 2012). Various consortia have formed to facilitate collaboration in IoT-ecosystems. Those include the Industry IoT Consortium (IIC) (Industry IoT Consortium, 2020), the Digital Twin Consortium (Digital Twin Consortium, 2020), and – in the domain of this paper's case – the initiative Handwerk 2025 (Handwerk 2025, 2022). Those have created a multitude of IoT-ecosystems. But how IoT-ecosystem form is not yet well understood in research.

The German craft sector is home to many SMEs (Fjeldsted, 2019). This sector is an important part of the German economy and home to one million enterprises according to the German confederation of skilled crafts (2022). Those SMEs benefit from their ability to innovate collectively (Engel et al., 2004). They are often led by the owners and produce highly specific items that require a fit to the surroundings (Glasl et al., 2008). The German craft sector is organized around strong trade associations. These sit at the center of their respective sectors, working on advancing the whole industry rather than the individual enterprise (Rothgang, 2003; Lawton et al., 2017). This structure in the current craft ecosystems positions them well to help introducing new technologies into their craft or trade (Newell and Swan, 1995). It puts trade organizations in the center of potential IoT-ecosystems. This poses the research question we seek to answer:

How can a craft ecosystem develop into an IoT-ecosystem?

A challenge in researching the early parts of such an IoT-ecosystem is gaining access to observe the process (Yin, 2018). We addressed this by initiating an IoT-ecosystem focused on the craft sector in Germany. We were able to work closely with the trade association in this ecosystem which allowed us access to the stakeholders during the process of developing the IoT-ecosystem. We used this access to conduct an explorative research study and create a phase structure for the emergence of IoT-ecosystems. Our research employed the design science research paradigm within the field of information systems (Peffers et al., 2007; Hevner and Chatterjee, 2010). We conducted interviews with experts in the craft sector to understand the status quo and derive insights for the further development into an IoT-ecosystem. These insights were combined with existing concepts to form the artifact of our research, the three-phased approach to IoT-ecosystem creation. The artifact was evaluated in a workshop with a panel of experts.

Related Work

Our research builds on work in the field of information systems. We took the concept of IoT and applied its paradigms to the creation of an IoT-ecosystem. To lay out the foundations of our research, we will first define IoT in our context and then show how current research combines it with research in ecosystems to form novel IoT-ecosystems.

Internet of Things

IoT is connecting physical objects over the internet (Xia et al., 2012). This simple basic definition has grown to encompass different additional aspects. The notion of a digital representation that makes the state of a physical object accessible has been widely employed to design such systems (Canedo, 2016). The physical object and its digital representation are connected by a two-way data connection (Tao et al., 2018). This connection allows the flow of the current physical state into the digital representation and enables the digital representation to control actions of the physical object (Lee, 2010; Gubby et al., 2013; Sunyaev, 2020). A digital representation allows the physical objects to be interoperable with other objects and digital services (Lin et al., 2016). Based on this technical definition of how physical objects are connected, a broader understanding of why physical objects should be connected in the first place developed in recent years. This broader definition of IoT does, for example, include the innovative applications IoT will enable (Gubby et al., 2013). An even wider perspective is contributed by Karmarkar et al. (2018) with their focus on achieving "transformational business outcomes". These outcomes may occur in an individual enterprise or a collection of enterprises working together, enabled by the interconnection of physical objects (Lin et al., 2017). These two perspectives are synthesized for the purpose of our research to yield the following definition: The Internet-of-Things aims to achieve transformational business outcomes by enabling enterprises to collaborate through connected physical objects.

IoT-Ecosystem

The study of collaboration between enterprises has a long history. At its core is the idea that enterprises should be viewed as parts of a bigger ecosystem (Moore, 1993). An ecosystem in general is made up of a central entity, such as a company, a platform, or a product and the related enterprises that are involved with it (Riasanow et al., 2021; Benedict, 2018). Technical innovation can act as a seed in such an ecosystem, around which enterprises form to "work cooperatively and competitively to support new products [...]" (Moore, 1993). These ecosystems are classified into different types by Faber et al. (2019). They distinguish between platform-, innovation-, and knowledge-ecosystems. Ecosystems that form around IoT as their seed are categorized as a subtype of platform-ecosystems by Faber et al. (2019). Platform-ecosystems differ from business-ecosystems in their focus on offering a platform instead of a product or service (Faber et al., 2019). IoT-ecosystems use a "[…] set of core assets related to the interconnection of the physical world of things with the virtual world of Internet" (Mazhelis et al., 2012). They form by attracting partners from different domains to create a common value scenario (Iansiti and Levien, 2004; Adner, 2017). IoT acts as an enabler for collaboration in those ecosystems (Mazhelis et al., 2012). It allows them to exchange information and create more value than an individual enterprise could (Weber et al., 2019). The study of IoT-ecosystems inherently lies at the intersection of technology and business (Leminen et al., 2012).

IoT-Ecosystems in the Craft Sector

IoT-ecosystems have not been well studied in the context of the craft sector especially in relation to, for example, the manufacturing sector. To confirm this assumption, we conducted a literature review of the Association for Information Systems' eLibrary (AISel) for literature on IoT-ecosystems in the craft sector. We wanted to search the broad field in general and therefore did not limit our search to results covering just SME. The number of research papers that include the term "craft sector" are put into context in Figure 1. The search was conducted in February 2022 in accordance with Levy and Ellis (2006) and Brocke et al. (2009). Identified relevant research is summarized below.

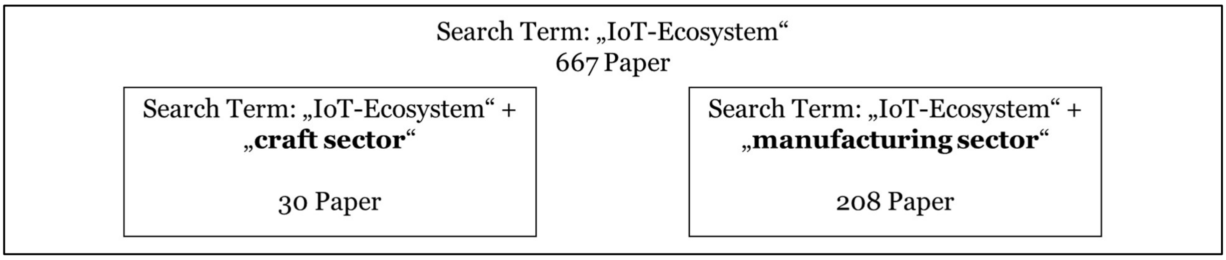

Figure 1. AISel literature review

Of the 30 papers that were identified by our search, only two are potentially relevant for Ecosystems in the craft sector. The 28 other papers were screened but did not focus on relevant aspects for our research. The two relevant papers differ in their focus. Gierlich et al. (2019) conducted a study on eleven SMEs to identify how their role in an ecosystem influences their path to digitalization. They adapted research by Schüritz et al. (2017) to form a 4-stage framework for digitalization development of SMEs. The four stages describe how an enterprise's digital offerings change by introducing digitalization, as shown in Table 1.

Stage	Description
0	No digital offerings
1	Data-enabled improvements in old business model
2	New product-related solutions in new business model
3	Stand-alone services in new business model

Table 1. Stages of Digitalization by Gierlich et al. (2019) adapted from Schüritz et al. (2017)

This approach focuses on changes to the individual enterprise's business model. It acknowledges the importance of platform ecosystems in enabling these but does not view the ecosystem as an entity offering value to third parties. Rauhut et al. (2021) identified requirements for platform-based ecosystems in the craft sector that are partly applicable to IoT-ecosystems. They structured the requirements into the categories of prerequisites, method, proof of concept, and usage. Our literature review shows the lack of research into how IoT-ecosystems develop from existing ecosystems.

Methodology

The aim of our research is to guide this development from an existing ecosystem into an IoT-ecosystem. Only few IoT-ecosystems have developed so far, and access during the formative early stages of an IoT-ecosystems development is near impossible. This lack of access presents a major obstacle in researching the process of IoT-ecosystem creation in a case study (Yin, 2018). To allow us to proceed with our research, we became part of a research project that initiated an IoT-ecosystem in electrical engineering. We chose the field of electrical engineering as our sample due to its potential to develop into an IoT-ecosystem as well as existing access to stakeholders within the ecosystem. This active involvement in the subject of study allowed us access into all facets of our case and to generate abstract scientific progress as expressed in the principles of dual scientific research (Weber et al., 2021). The project enabled us to conduct interviews with participants, observe the implementation of a proof of concept in the first phase, and conceptually develop the subsequent two phases by combining insights from our case with current literature. The three-phased approach was later evaluated in a workshop. In addition, we evaluated our artifact with respect to its feasibility in a real-life setting. Our research structure is shown in Figure 2.

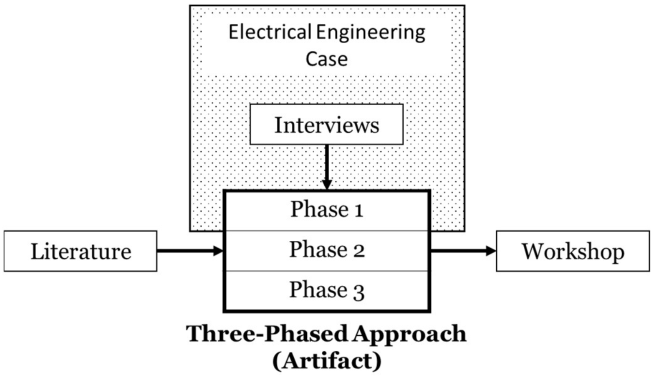

Figure 2. Research structure

We began our explorative research by understanding the participants field of work and the associated challenges. We conducted and recorded semi-structured interviews with the participants and observed two of them on a typical work assignment (Atteslander, 2010). During the direct observation, the researchers took notes. The notes were parsed for relevant information as recommended by Mayring (2004). Relevant information included: the as-is state, typical issues during the daily assignments, typical issues regarding the data processing, and potential problems during the transformation. These insights, combined with literature on building IoT-ecosystems in other domains, enabled us to create the three-phased approach in close collaboration with the trade association. All three phases of the approach were evaluated for their feasibility in a workshop with all participants.

#	Participants	Location	Length	Interview Focus
1	CEO, trade association representative, two developers, four researchers	online	~1h	How IoT provides value
2	CEO, trade association representative, developer, four researchers	online	~1.5h	How IoT provides value
3	Electrician, two researchers	on-site	~1.5h	How business is conducted today
4	Electrician, one researcher	on-site	~2.5h	How business is conducted today
5	Craft association representative, one researcher	on-site	~1h	How business is conducted today

Table 2. Expert Interviews

The project was conducted from February to December 2020 in collaboration with a research institute that focuses on business intelligence & analytics and a software development company. The trade association was a partner in the project. The initial interviews were conducted with the Chief Executive Officers (CEOs) of two representative enterprises in the trade associations network. An additional interview was conducted with a craft association representative to better understand how business is conducted today. The interviews covered different viewpoints on the topic, such as the business perspective, the strategy perspective, the technical infrastructure perspective, the information technology perspective, and the worker's perspective. These different perspectives provided a broad foundation for our artifact. Each expert has worked in their position for more than 5 years and can therefore be considered a reliable source of insights. This initial exploration took place in the first half of the research project and allowed us to combine literature with our findings, creating the three-phased approach. A prototype system of phase 1 was then built during the project and put into trial use by the trade association. This system allowed the participants to experience phase 1 of the artifact in a limited real-life setting. The artifact was evaluated in a half-day workshop in accordance with March and Smith (1995) by a panel of five domain experts. The authors and two additional Researchers took part in the workshop and documented their observations. The first half of the workshop focused on conveying the artifact and additional results of the case study. Participants discussed these findings during the second half of the workshop.

Results

Our case study was conducted in the German electrical engineering sector. This sector is classified as a skilled craft in Germany and work is regulated by local chambers of trade. The main tasks that fall into the category of the electrical engineering trade are installing and maintaining electrical systems in buildings. Besides ensuring the safety of everyone that works or lives in buildings with electricity (German Institute for Standardization, 2015), this makes the trade an important cornerstone in the transition to green energy production and electric personal mobility (Kohl, 2018). Both rely on electrical systems in buildings to not only maintain their current functionality but to expand it significantly (Kohl, 2018). These challenges combined with new opportunities through digital technologies, form the base of our case study.

We structured the development of an IoT-ecosystem into three phases. The initial state represents the state of the ecosystem before starting the process of IoT-ecosystem creation. In our case, the trade association produces supporting material for enterprises and helps them train employees. Individual enterprises assess their clients' systems and process data themselves in accordance with federal regulation (German Institute for Standardization, 2015; German Institute for Standardization, 2017). Data from the enterprises' clients is collected periodically by skilled professionals assessing the clients' electrical systems (Faber et al., 2012; Rudnik, 2022). Relevant data is gathered and processed into information, for example into recommendations for clients. The data acquisition process is done manually by inspecting the clients' systems on premise and testing predefined characteristics on a predefined schedule, commonly every two years. The gathered inspection data of clients' systems, like insulation resistance and ground resistance, are processed into actionable information for the client. This processing might be simple thresholds or more complex patterns identified by the individual expert on premise. Processed data is not transmitted onward to the trade association or other enterprises. The trade association is not directly involved in processing data into information. Individual enterprises are therefore required to process their inspection data. They mostly lack inter-enterprise connections to collectively share and process data. In case of a client changing from one enterprise to another, information is lost, as important historical context is not available to the new enterprise. This leads to additional effort for the new enterprise and creates opportunities for collaboration. The trade association is in a prime position in the craft sector to lead the whole ecosystem towards realizing these opportunities by building an IoT-ecosystem.

Based on our research, we propose a three-phased approach to develop a craft ecosystem into an IoT-ecosystem. These phases have been designed to build on each other and should therefore be understood to be sequential. Each phase will be introduced below. The first phase was implemented in a real-world setting, phases 2 and 3 were designed as next steps to fully develop the ecosystem into an IoT-ecosystem.

Phase 1 – Adaption

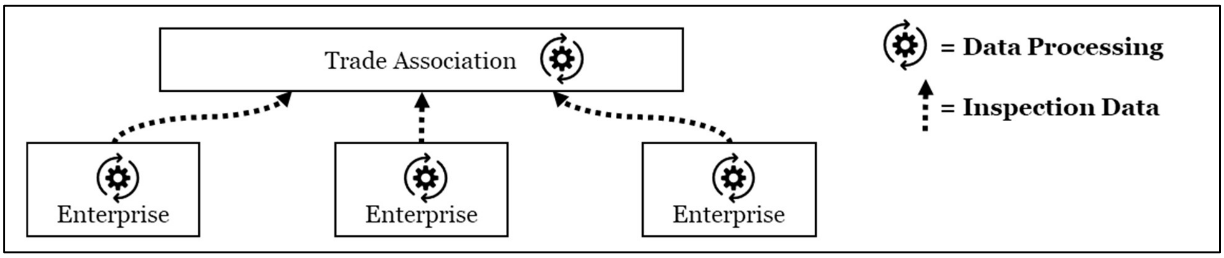

Figure 3. Inspection data is transferred and collectively processed

Sharing information with others in the ecosystem is not part of the everyday workflow of the enterprises. They normally create information for themselves or their clients. The first phase shows enterprises that sharing their information through the trade association is beneficial for all of them. It also relates back to one of the core principals of trade associations: working collectively benefits all members (Lawton et al., 2018). This is achieved by transmitting existing information onward to the trade association and having it processed further on this inter-enterprise level. The trade association applies advanced analytic and statistic methods on the combined inspection data that is collected by enterprises during the assessments of their clients' electrical systems. The resulting new information is then made available for all participating enterprises. This creates value for the participating enterprises while not requiring a huge upfront investment. Enterprises are often reluctant to head into a project that requires a big upfront investment before tangible benefits have been experienced. This is especially true in the craft sector.

In our proof-of-concept implementation of phase 1, we designed different value scenarios and discussed them with the CEOs in our interviews. The CEOs were asked to provide feedback on all these scenarios. The best ranking scenario was picked after the interviews to guide the proof-of-concept implementation of phase 1. In this scenario the trade association identifies patterns of common faults in electrical systems and devices. Using these patterns, the association can alert enterprises of potential system malfunctions before they happen. This scenario was built into a proof-of-concept that processes inspection data from enterprises at the trade association and identifies patterns in the data. One example is the application of the support vector machine algorithm (Noble, 2006) to identify faults in the collected data. Using the combined inspection data to train the support vector machine resulted in 91% accurate predictions in a validation sample. The results of this proof-of-concept were presented together with the entire three-phased approach at the evaluation workshop and discussed with the participants. The experts see value in the generated information and are interested in further developing the nascent IoT-ecosystem.

Phase 2 – Foundation

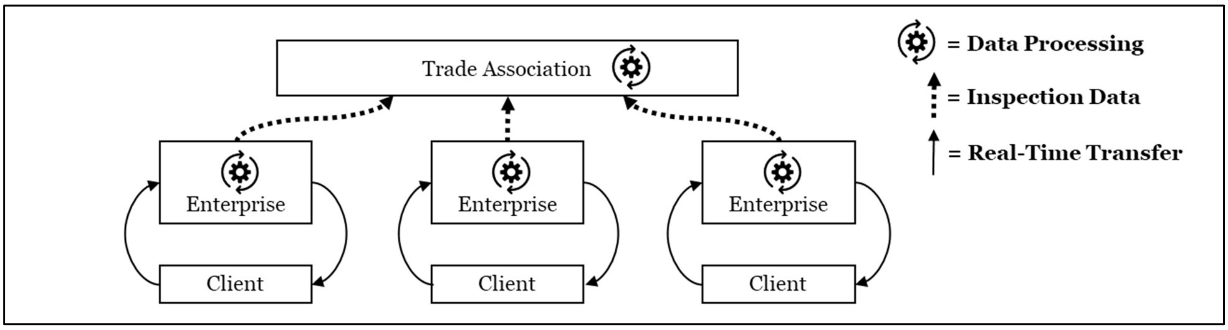

Figure 4. Enterprises introduce IoT

Enterprises in the electrical field normally visit their clients' systems every two years. These visits are conducted to assess the current state of these systems. The second phase introduces the principles of IoT to connect the clients' systems in real time (Lee, 2010; Gubby et al., 2013; Sunyaev, 2020). This connection allows enterprises to have near real time access to the current state of physical systems (Delicato et al., 2013). This enables them to monitor clients' systems continuously and avoid harmful states of the system as well as unscheduled downtime. It also improves the quality of information that can be processed by the trade association. One important factor is that the type of information transmitted to the trade association stays of the same kind as in phase 1. If, for example error states and their associated measurements, are to be transmitted to the trade association, then those will just be transmitted timelier by enterprises in phase 2. It stays backward compatible with enterprises that, for whatever reason, chose to stay at phase 1. This property allows enterprises to proceed in accordance with their own schedule and makes the approach more resilient in its development. Some enterprises might want to see others benefit from the investment in connecting their clients' systems before acting themselves.

Phase 3 – Opening

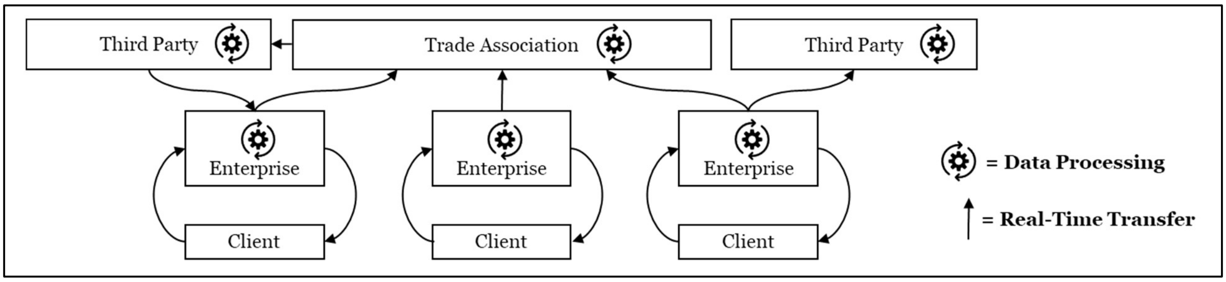

Figure 5. The ecosystem opens, so everyone can interact in an IoT-ecosystem

Enterprises experience the benefit of sharing information in their ecosystem in phase 1 and the benefits of having real time connections to their clients in phase 2. The third phase combines both to create an open IoT-ecosystem of real time information exchange. This openness allows the participants to benefit from the others' capabilities as described by Weber et al. (2019). An individual enterprise can for example improve its services to its clients by having data analyzed by a third party and compared to common error types by the trade association. An important distinction to the first two phases, is the extension of real time flows of data and resulting information to the entire IoT-ecosystem. This IoT-ecosystem is extended to third parties that may be able to provide useful capabilities or insights to improve the enterprises' services. Having access to the detailed information, such an arrangement can provide, constitutes a competitive advantage (Laney, 2017). Enterprises share data amongst each other freely, while monetizing information that is created by processing data with unique capabilities of the individual enterprise.

Discussion

Following the three-phased approach to developing ecosystems into IoT-ecosystems allows SMEs in the craft sector to potentially achieve the transformational business outcomes that Karmarkar et al. (2018) identified. The approach allows individual enterprises to proceed at their own pace through the different phases while guiding them towards creating an IoT-ecosystem. The transformation is enabled by the interconnection of physical objects as described by Lin et al. (2017). Objects are being connected through the IoT in phase 2 with further connections added in phase 3. This allows the enterprises to create value by exchanging information with each other as described by Weber et al. (2019). The first phase can be seen as unlocking the first stage of business value in the staged approach by Gierlich et al. (2019). Our three-phased approach differs from the staged approach by Gierlich et al. (2019) in its focus on how business value can be created by building IoT-ecosystems. The business value stages may emerge in IoT-ecosystems build by using our three-phased approach. The three-phased approach will allow researchers to observe the added value in the individual phases. This might provide insight into the difference in building platform-ecosystems as opposed to IoT-ecosystems in the context of the craft sector. This in turn will provide clarity on the applicability of the requirements identified by Rauhut et al. (2021).

Trade associations can take the three-phased approach and use it to guide their ecosystem to develop into an IoT-ecosystem. This will allow them to create new value within their own ecosystem and add value to third parties (Schladofsky et al., 2016). Third parties can easily be integrated due to the interoperability inherent to IoT-ecosystems (Lin et al., 2016). Participants in the evaluation discussed the feasibility and usability of the artifact and concluded that the artifact is providing value in practical implementation for their business.

Limitations and Further Research

Our research assumes added value through IoT-ecosystems as a net positive for all participants. This assumption should be tested with more quantifiable methods like the one by Lopez et al. (2021). We focus on the narrow niche of trade associations and enterprises within the field of electrical engineering. In a first discussion, we assessed a possible extension of the approach to the heating, ventilation, and air conditioning (HVAC) industry. A wider applicability of our approach is therefore assumed, but not rigorously evaluated yet. This limitation stems from the explorative approach of our research and should be addressed once access to more cases is possible. Future research should clarify how the different phases fit into existing legal frameworks for data sharing ecosystems, especially if they encompass entire sectors as presented by Kerber (2019). Trade associations are potentially well placed in the current ecosystem to facilitate the sharing of nonmarket information (Rajwani et al., 2015; Vives, 1990). The involvement of trade associations in general is a facilitator in the development into an IoT-ecosystem. They can provide funding and are an established, trusted partner in the existing ecosystem.

When opening the IoT-ecosystem in the third phase, partners in the ecosystem interact with outside third parties. Establishing a secure mode of interaction with potentially untrusted parties is a big challenge in the implementation of this phase. Technical solutions, like for example the use of distributed ledger technology as proposed by Ranathunga et al. (2020), could yield a possible way forward. Secure interactions with untrusted and unknown parties in a world without trusted intermediaries are an open area of research.

Conclusion

IoT-ecosystems enable SMEs in the craft sector to work together to unlock new value. Trade associations are well positioned to facilitate this development into IoT-ecosystems. We present a three-phased approach to develop an existing craft ecosystem into an IoT-ecosystem. The first phase adapts current processes in a way that is simple but yields initial benefits for all. Enterprises build their individual IoT systems in the second phase. The third phase focuses on connecting those individual IoT systems into an IoT-ecosystem. Thinking in IoT-ecosystems opens the scope to include external third parties that benefit from generated information or might offer useful services to the ecosystem.

Acknowledgements

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REFERENCES

Adner, R. 2017. “Ecosystem as structure,” *Journal of Management* 43.1, pp. 39-58.

Atteslander, P. 2010. *Methoden der empirischen Sozialforschung*. 13th ed, Berlin, Erich Schmidt Verlag.

Benedict, M. 2018. “Modelling Ecosystems in Information Systems – A Typology Approach,” *Proceedings of the Multikonferenz Wirtschaftsinformatik.*

Brocke, J. V., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., and Cleven, A. 2009. “Reconstructing the giant: on the importance of rigour in documenting the literature search process,” *17th European Conference on Information Systems* (ECIS 2009).

Canedo, A. 2016. “Industrial IoT lifecycle via digital twins,” *Proceedings of the Eleventh IEEE/ACM/IFIP International Conference on Hardware/Software Codesign and System Synthesis* (CODES 16).

Delicato, F.C., Pires, P.F., Batista, T., Cavalcante, E., Costa, B., and Barros, T., 2013. “Towards an IoT ecosystem,” *Proceedings of the 1st international workshop on software engineering for systems-of-systems*, pp. 25-28.

Digital Twin Consortium. 2020. “Object Management Group Forms Digital Twin Consortium with Founders Ansys, Dell Technologies, Lendlease, and Microsoft,” Digital Twin Consortium, May 18. (https://www.digitaltwinconsortium.org/press-room/05-18-20.htm, accessed January 25, 2022).

Engel, D., Rothgang, M., and Trettin, L. 2004. “Innovation and their impact on growth of SME–Empirical evidence from craft dominated industries in Germany,” *EARIE 2004 Conference*, pp. 2-5.

Faber, A., Riemhofer, M., Rehm, S.-V., and Bondel, G. 2019. "A systematic mapping study on business ecosystem types," *Americas Conference on Information Systems* (AMCIS), Cancún.

Faber, U., Grapentin, M., and Wettingfeld, M. 2012. *Prüfung elektrischer Anlagen und Betriebsmittel-Grundlagen und Methoden*. vol. 3, VDE-Schriftenreihe – Normen verständlich Volume 124.

Fjeldsted, T. 2019. "Handwerk: Crafts and Trades in Germany," *A Cultural Economic Analysis of Craft*.

Friedow, C., Völker, M., and Hewelt, M. 2018. "Integrating IoT Devices into Business Processes", in: *Matulevičius R., Dijkman R. (eds) Advanced Information Systems Engineering Workshops*. CAiSE 2018. Lecture Notes in Business Information Processing, vol 316., Cham, Switzerland: Springer.

German Confederation of Skilled Crafts. 2022. "The Skilled Crafts Sector," German Confederation of Skilled Crafts. (https://www.zdh.de/english/the-skilled-crafts-sector/, accessed February 22, 2022).

German Institute for Standardization. 2015. "DIN VDE 0105-100 Part 100: Operation of electrical installations," Berlin: VDE Verlag.

German Institute for Standardization. 2017. "DIN VDE 0100-600 Part 6: Verification," Berlin: VDE Verlag.

Gierlich, M., Schüritz, R., Volkwein, M., and Hess, T. 2019. "SMEs' approaches for digitalization in platform ecosystems," *Pacific Asia Conference on Information Systems* (PACIS 2019).

Glasl, M., Maiwald, B., and Wolf, M. 2008. *Handwerk: Bedeutung, Definition, Abgrenzung*. Ludwig-Fröhler-Institut für Handwerkswissenschaften, Munich.

Gubbi, J., Buyya, R., Marusic, S., and Palaniswami, M. 2013. "Internet of things (IoT): a vision, architectural elements, and future directions," *Future Generation Computer Systems* 29.7, pp. 1645-1660.

Handwerk 2025. 2022. "Zukunftsinitiative Handwerk 2025 – Dein Werkzeug für Morgen," (*https://handwerk2025.de/*, accessed February 18, 2022).

Hevner, A., and Chatterjee, S. 2010. *Design science research in information systems*. Springer, Boston.

Iansiti, M., and Levien, R. 2004. "Strategy as ecology," *Harvard Business Review* 82.3, pp. 68-78.

Industry IoT Consortium. 2020. "Industrial Internet Consortium pivots to reflect maturity of IoT marketplace," (https://www.iiconsortium.org/press-room/08-17-21.htm, Industrial IoT Consortium, accessed January 25, 2022).

Jacobides, M. G., Cennamo, C., and Gawer, A. 2018. "Towards a theory of ecosystems," Strategic management journal 39.8, pp. 2255-2276.

Karmarkar, A., Hirsch, F., Bournival, E., Buchheit, M., Simmon, E., and Sobel, W., et al. (2018). "The industrial internet of things: volume G8: vocabulary," *Industrial Internet Consortium*.

Kerber, W. 2019. "Data sharing in IoT ecosystems and competition law: the example of connected cars," *Journal of Competition Law & Economics*, 15(4), pp. 381-426.

Kiel, D., Müller, J. M., Arnold, C., and Voigt, K.-I. 2017. "Sustainable industrial value creation: benefits and challenges of industry 4.0" *International Journal of Innovation Management*.

Kohl, M. 2018. "Elektromobilität, Digitalisierung und Industrie 4.0 als Innovationstreiber–neue Produkte und Produktionsprozesse bedingen neue Kompetenzanforderungen," in *Auswirkungen der Elektromobilität auf die betriebliche Aus- und Weiterbildung*, S. Kretschmer, I. Pfeiffer and G. G. Goth (eds.), Bielefeld, Germany: wbv Publikation, pp. 11-32.

Koo, B.-S., and Lee, C.-Y. 2018. "The moderating role of competence specialization in the effect of external R&D on innovative performance," R&D Management 49.4, pp. 574-594.

Laney, D. 2017. *Infonomics. How to Monetize, Manage and Measure Information as an Asset for Competitive Advantage*. Routledge.

Lawton, T.C., Rajwani, T., and Minto A. 2018. "Why trade associations matter: exploring function, meaning, and influence," *Journal of Management Inquiry* 27.1, pp. 5-9.

Lee, E. A. 2010. "CPS foundations," *Design Automation Conference*, IEEE, pp. 737-747.

Leminen, S., Westerlund, M., Rajahonka, M., and Siuruainen, R. 2012. "Towards IoT ecosystems and business models," *Computer communication networks and telecommunications 7469*, pp. 15-26.

Levy, Y. and Ellis, T. 2006. "A systems approach to conduct an effective literature review in support of information systems research," *Informing Science 9*.

Lin, S.-W., and Miller, B. 2016. "Industrial internet: towards interoperability and composability," *IIC*.

Lin, S.-W., Miller, B., Durand, J., Bleakley, G., Chigani, A., and Martin, R., et al. 2017. "The industrial internet of things volume G1: reference architecture," *Industrial Internet Consortium*.

Lopez, C.A., Castillo, L.F. and Corchado, J.M. 2021. "Discovering the Value Creation System in IoT Ecosystems," *Sensors*, 21(2), pp. 328.

March, S. T., and Smith, G. F. 1995. "Design and natural science research on information technology," Decision support systems 15(4), pp. 251-266.

Mayring, P. 2004. "Qualitative Content Analysis," A Companion to Qualitative Research 1.2, pp. 159-176.

Mazhelis, O., Luoma, E., and Warma, H. 2012. "Defining an Internet-of-Things ecosystem," in *Lecture Notes in Computer Science*, volume 7469 LNCS, Institute of Electrical and Electronics Engineers, Inc.

Moore, J. F. (1993). "Predators and prey: a new ecology of competition," *Harvard Business Review* 71.3.

Newell, S., and Swan, J. 1995. "Professional associations as important mediators of the innovation process," *Science Communication*, *16*(4), pp. 371-387.

Noble, W. 2006. "What is a support vector machine," *Nature Biotechnology* 24, pp. 1565-1567.

Parker, D. S. 2020. "The Implementation of the Internet of Things (IoT): A Case Study of the Barriers that Prevent Implementation of IoT within Small and Medium Enterprises (SME)," Northcentral University.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. 2007. "A design science research methodology for information systems research" *Journal of Management Information Systems* 24.3.

Prasse, C., Nettstraeter, A., and Hompel, M. T. 2014. "How IoT will change the design and operation of logistics systems," *2014 International Conference on the Internet of Things (IOT)*, pp. 55-60.

Rajwani, T., Lawton, T., and Phillips, N. 2015. "The "voice of industry": why management researchers should pay more attention to trade associations," *Strategic Organization* 13.3, pp. 224-232.

Ranathunga, T., Marfievici, R., McGibney, A., and Rea, S. 2020. "A DLT-based trust framework for IoT ecosystems," *2020 International Conference on Cyber Security and Protection of Digital Services*.

Rauhut, A., Hiller, S., and Lasi, H. 2021. "Requirements to Enable Platform-based Ecosystems in the Craft Sector," *Pacific Asia Conference on Information Systems* (PACIS 2021).

Riasanow, T., Jäntgen, L., Hermes, S., Böhm, M., and Krcmar, H. 2020. "Core, intertwined, and ecosystem-specific clusters in platform ecosystems: analyzing similarities in the digital transformation of the automotive, blockchain, financial, insurance and IIoT industry," *Electronic Markets* 31.1, pp. 89-104.

Rothgang, M., and Trettin, L. 2003. "Strengthening the German Craft sector through Innovation and Cooperation," *43rd Congress of the European Regional Science Association* (ERSA).

Rudnik, S. 2022. *Prüfung elektrischer Anlagen und Ausrüstungen*. vol 2, VDE-Schriftenreihe – Normen verständlich Volume 163.

Schladofsky, W., Mitic, J., Megner, A. P., Simonato, C., Gioppo, L., and Leonardos, D., et al. 2016. "Business models for interoperable IoT ecosystems," *International Workshop on interoperability and Open-Source Solutions,* Cham, Switzerland: Springer, pp. 91-106.

Schüritz, R., Seebacher, S., Satzger, G., and Schwarz, L. 2017. "Datatization as the next frontier of servitization – understanding the challenges for transforming organizations," *International Conference on Information Systems* (ICIS 2017).

Stummer, C., Kundisch, D., and Decker, R. 2018. "Platform launch strategies," *Business & Information Systems Engineering* (60), pp. 167-173.

Sunyaev, A. 2020. "The internet of things," *Internet Computing*, Springer, Cham, 301-337.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H. and Sui, F. 2018. "Digital twin-driven product design, manufacturing and service with big data," *The International Journal of Advanced Manufacturing Technology*, 94(9-12), pp. 3563–3576.

Teece, D. J. 2017. "Dynamic Capabilities and (Digital) Platform Lifecycles," *Entrepreneurship, innovation, and platforms (Advances in Strategic Management 37)*, J. Furman, A. Gawer, B. Silverman, and S, Stern (eds.), Emerald Publishing Limited.

Tiwana, A. 2014. *Platform ecosystems: Aligning architecture, governance, and strategy*. Morgan Kaufmann.

Vives, X. 1990. "Trade association disclosure rules, incentives to share information, and welfare," *The RAND Journal of Economics 21.3*, pp. 409-430.

Weber, P., Hiller, S., and Lasi, H. 2019. "Design and evaluation of an approach to generate cross-domain value scenarios in the context of the industrial internet of things: a capability-based approach," *Portland International Conference on Management of Engineering and Technology* (PICMET), Portland.

Weber, P., Hiller, S., and Lasi, H. 2021. "Dual Scientific Research Framework – Generating Real World Impact and Scientific Progress in Internet of Things Ecosystems," *Pacific Asia Conference on Information Systems* (PACIS 2021).

Xia, F., Yang, L.T., Wang, L., and Vinel, A. 2012. "Internet of Things," *International Journal of Communication Systems 2012* (25), pp. 1101-1102.

Yin, R. K. 2018. *Case Study Research and Applications. Design and Methods*. vol.6, Thousand Oaks, CA.: SAGE Publications.