Methods for Model-Driven Development of IoT Applications: Requirements from Industrial Practice

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Abstract: The Internet of Things (IoT) has become a crucial topic in research and industry over recent years. Enterprises often fail to create business value from IoT technology because they have difficulties defining organizational integration. Model-driven Development (MDD) is considered an effective technique for IoT application development. We argue that methods for MDD should comprise the organizational as well as the system development and integration. This paper aims to provide an overview of the current state of research on MDD of IoT applications. For this purpose, we conducted a structured literature review (SLR). A research gap was identified as no specific research could be found on MDD of IoT applications with a focus on organizational and system aspects. We also derived requirements from an industrial use case. The main contributions of this paper are (a) requirements from medium-sized enterprises (SMEs) to methodical and technical IoT development support derived from a use case, (b) the results of a systematic literature analysis in this field, and (c) an initial structure for the methodical support and initial architecture for the accompanying tool support.

1 INTRODUCTION

From the initial technological idea in the late 1990s to extend the reach of the Internet also to include physical "things", the Internet of Things (IoT) concept developed into an essential element in digital transformation and the Internet economy (Hansen and Bøgh, 2021). Many physical devices, like vehicles, household devices, or production lines in manufacturing, are equipped with sensors and control units connected to the Internet, which facilitates IoT-enabled services, such as remote monitoring and control, predictive maintenance, or product-as-a-service. IoT can be defined as the "seamless interplay among dynamic communities of human users, conventional computer systems, and smart objects, which interact with each other and the surrounding environment" (Fortino et al., 2015). Other technological trends, such as cyber-physical systems (CPS) and industry 4.0 (Horvath and Gerritsen, 2012), or new business models, such as smart connected products (Porter and Heppelmann, 2015), data-driven services, and quantified products (Sandkuhl, 2022), supported the development of infrastructures and organizational models related to IoT.

From a research perspective, there is a substantial body of knowledge on technological and development aspects of how to specify, design, and implement IoT solutions (Alberti et al., 2019; Fortino et al., 2015). However, our observation is that many, primarily small and medium-sized enterprises (SMEs), hesitate to invest in IoT efforts because they consider the development processes too complex and have difficulties designing the organizational integration (Sandkuhl and Seigerroth, 2021). The motivation for our work is that existing model-based approaches for IoT solutions focus on the software and systems perspective and show a need for more integration with organizational and business model aspects. We argue that methodologies for model-driven development (MDD) of IoT solutions need to be better prepared for use in SMEs and should also include organizational integration. This viewpoint is confirmed by the findings of (Fortino et al., 2021), who state that the IoT development products, such as methodologies, frameworks, platforms, and tools, mainly focus on the software components of IoT systems.

The long-term objective of our work is to develop methodical and technological support tailored to the

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needs of SMEs that allows for the implementation of IoT solutions integrating business (i.e., business model and organizational integration) and IT aspects (i.e., software and systems engineering). The main contributions of this paper are (a) requirements from SMEs to methodical and technical IoT development support derived from a use case, (b) the results of a systematic literature analysis in this field, and (c) an initial structure for the methodical support and an initial architecture for the accompanying tool support.

The paper is structured as follows: Section 2 briefly introduces the research method used in our work. Section 3 summarizes the state-of-the-art in IoT development methodologies and specifics of SMEs to be taken into account in methodology development. Section 4 introduces the industrial case study motivating our work and requirements for methodologies from an SME perspective. Section 5 presents a literature study on method support for IoT development. Section 6 presents the initial version of methodical and technical development support for SMEs. Section 7 summarizes findings and future work.

2 RESEARCH METHOD

Research work in this paper started from the following research question, which is based on the motivation presented in section 1: RQ: When implementing IoT solutions in SMEs, what are the enterprises' requirements for methodical and technological support, to what extent are these requirements covered by existing methodologies, and how should the methodical/technical support look like?

The research method used for working on this research question is a combination of literature study, descriptive case study, and argumentative-deductive work. Since our previous work (see (Nast and Sandkuhl, 2021)) indicated that the specifics of SMEs were not sufficiently represented in existing work and not well understood, we decided to perform a case study to gather information pertinent to the subject area. A qualitative case study is an approach to research that facilitates the exploration of a phenomenon within its context using various data sources. This ensures that the subject under consideration is not explored from only one perspective but rather from various perspectives, allowing for multiple facets of the phenomenon to be revealed and understood. Within the case study, we used three different perspectives, which at the same time represent sources of data: we observed the activities during IoT development, examined the enterprise's business model, and interviewed different roles involved. Yin differentiates various kinds of case studies (Yin, 2009): explanatory, exploratory, and descriptive. The case study presented in section 4 has to be considered descriptive, as it describes the phenomenon of process outsourcing and the real-life context in which it occurs.

Based on the research question defined and the requirements visible in the case study, we started identifying research areas with relevant work for this question and analyzed the literature in these areas. The purpose of the analysis was to find existing theories, methods, or technologies that guide the implementation of IoT solutions in SMEs from both IT and business perspectives. Due to the focus on SMEs, the specific characteristics of SMEs had to be identified and taken into account before starting the literature analysis (see section 3.2). Section 5 presents and discusses the results of the literature study. Based on the case study results and the literature study results, we propose an initial structure of the method and an architecture for the method's tool support. This argumentative-deductive part of our work is the subject of section 6. The overall research project follows the ideas and principles of design science research (Hevner et al., 2004) with the methodical and technical support being the core artifact. In our previous work, we investigated the need for a domain-specific modeling language (DSML) by analyzing business needs in a use case and existing literature in the field of DSML in IoT (Nast and Sandkuhl, 2021). This confirmed the relevance of research in modeling IoT solutions and forms the starting point for this paper. The next step is to understand the requirements for the application of models in developing IoT applications, i.e., model-based development of IoT, and the possibility of reusing procedural or conceptual knowledge from existing methods. To investigate the former, as also mentioned above, we use an industrial case study and investigate the requirements. For the latter, a literature analysis was performed that also takes into account the results of the requirement analysis from the industrial case. As a conclusion for both steps, we identify future tasks in method development for MDD of IoT solutions.

3 BACKGROUND

This section describes the required theoretical background for this research approach. Section 3.1 focuses on IoT and MDD. Specifics of non-IT SMEs in this context are described in section 3.2.

3.1 Internet of Things and MDD

The IoT has become an important topic in research and industry, contributing to digital transformations in many industrial domains (Hansen and Bøgh, 2021). IoT technologies are at the center of industry 4.0 application scenarios and support the implementation of CPS. Many approaches are available today to support the specification, design, and implementation of IoT solutions (Fortino et al., 2021) from a technological and development perspective. However, many enterprises are still struggling to derive business value from IoT technology or are reluctant to invest in IoT efforts because of difficulties in defining organizational integration (Sandkuhl and Seigerroth, 2021).

There have been many approaches proposed to cope with the complexity of developing IoT solutions and improve their portability (Fortino et al., 2015). MDD is based on the concepts of software engineering and diagrams and is considered an effective technique for managing the complexity of IoT applications (Sosa-Reyna et al., 2018). To model a system and describe an architecture and functionality is more efficient for developers than to describe, document, and code every system detail in a programming language (Atkinson and Kuhne, 2003). Using MDD in this way, developers can engage with high-level abstractions to meet their system requirements and then automatically generate the necessary code (Kelly and Tolvanen, 2008). Existing model-based approaches also focus on requirements from a technical perspective and show a lack of integration with the day-to-day processes they should be supporting. The results of (Fortino et al., 2021) state that the IoT development products, such as methodologies, tools, platforms, and frameworks, mainly focus on the software components of IoT systems, thus confirming this view.

Defining a DSML to describe system requirements enables the use of MDD. Compared to general modeling languages, DSMLs are easier to specify, understand, and maintain (Frank, 2013). A defined syntax, semantics, or both, preserves the integrity of the models (prevents nonsensical models). Moreover, often a concrete syntax in the form of a special graphical notation for a DSML is given that helps to improve the clearness and understanding of the models.

3.2 Specifics of SMEs in Organizational Innovation

The specifics of SMEs have been well-researched when it comes to the introduction of technological innovations, such as the IoT. One stream of work in this field concerns the "readiness" of organizations for innovations, which aims at identifying aspects and factors affecting the introduction of innovations into an enterprise. Based on general observations when introducing information technology by (Snyder-Halpern, 2001), various adaptations for specific fields were proposed, such as service innovation readiness (Yen et al., 2012) or readiness for Artificial Intelligence (Jöhnk et al., 2021). In this work, the factor of digital innovation readiness seems to be most suitable to identify the specifics of SMEs that have to be observed when developing MDD support tailored for SMEs. These aspects are (Lokuge et al., 2019):

- Resource readiness describes how flexible financial, technological, and human resources that are required for digital innovation can be used in an enterprise. Essentially, this addresses the aspect of whether an enterprise has sufficient resources.
- IT readiness describes the quality of the IT portfolio to facilitate digital innovation. Here, the existence of the required IT infrastructure and accessibility of digital technologies is in focus.
- Cognitive readiness concerns the knowledge base in an organization needed for digital innovation, i.e., are the right competencies and the right knowledge available?
- Partnership readiness addresses the aspect of external stakeholders and their view on an organization's digital innovation. This includes partners, suppliers, and even customers.
- Cultural readiness concerns the core values of an organization and how they facilitate digital innovation, for example, by a culture of sharing of ideas, decentralized decision-making culture, or risk-taking.
- Strategic readiness addresses the set of managerial activities available to facilitate digital innovation, i.e., are there sufficient managerial and leadership competencies.

We argue that a methodology for IoT introduction should take into account the specifics of SMEs for all these factors. SMEs are characterized by:

- Resource: compared to larger enterprises, SMEs have less flexibility in the assignment of resources to technology innovation projects. Thus, they aim at projects with clearly defined and stable resource requirements.
- IT: the IT situation is strictly defined by organizational needs. IT introduction, as such, is often connected to or seen as innovation.
- Cognitive readiness: SMEs focus on the availability of competency and knowledge required for

their core business. Competencies in areas of innovation usually are present if the subject of innovation is in the core area.

- Partnership: there is no general pattern of readiness when it comes to customers, suppliers, or partners of SMEs, as the readiness of these groups highly depends on the domain and business model of the SME.
- Cultural readiness is highly dependent on the owners of an enterprise and the organizational culture they accept. Innovative owners tend to have a higher openness to technological innovations.
- Strategic readiness usually is limited as SMEs have management personnel that often has a multitude of tasks in their responsibility, which reduces the capacity for new activities.

In this context, we explicitly exclude SMEs from the IT sector as they usually have competencies in the area of IoT, i.e., the focus is on non-IT SMEs.

4 INDUSTRIAL CASE: IoT FOR ACT FACILITIES

In this section, the use case from industrial practice is presented. First, the use case company and the application context are described in section 4.1. The specific details and resulting requirements are described in section 4.2.

4.1 Case Company and Application Context

The method support work for integrating organizational aspects into IoT development methods is based on an industrial use case from the air conditioning and cleanroom technology (ACT) sector. Additional sensors and control systems need to be integrated and connected to a network in ACT facilities to enable energy optimization and a basis for predictive maintenance. The result is an IoT solution that forms the basis for new business services. Inspections of air handling units in operation often reveal significant discrepancies from the assessed energy efficiency. As the control technology becomes more automated, the amount of data is increasing sharply. Operating the direct and indirect processes of ACT facilities in an energy-efficient or -optimal manner needs intelligent data processing. Therefore, the demand for system solutions for self-recognition and self-organized learning and the control of the systems is high.

The planned IoT solution is intended to provide diagnostic support for possible optimizations in ACT facilities and for the operational processes of the case study company. Such a solution must be able to process a large amount of information from different sources and must be integrated into the operational processes of the case study company to support new types of services.

4.2 Use Case and Resulting Requirements

In collaboration with the case study company, requirements for the intended system were derived. To do this, employees of the case study company first described all the desired functions of the overall system. A description has been developed for each requirement, along with guidelines on how to achieve the desired goal. Those include required technical capabilities and outputs, respectively, functions of the human interface. Based on this information, it was then possible to identify and specify the required data for each requirement (e.g., origin or required recording duration and measurement accuracy). The requirements were then prioritized in terms of their importance and feasibility for the project (see Table 1).

Table 1: Requirements from use case.

Priority	Requirement
	Interoperability
1	Maintenance Support
2	Detect Disruptions
2	Recognise Operating Errors
2	Energetic Inspection
3	Detect Rule Errors
4	Predictive Maintenance
4	Dynamically Adjust Maintenance Cycles
5	Contracting
5	Facility Dimensioning
5	Commissioning

The following is a brief explanation of the requirements. Two of them are then described in more detail.

The overarching requirement is the *Interoperability* of the overall system. This means that the implementation using new sensors or a new measuring kit and the connection to existing building control systems must be possible. Furthermore, flexibility regarding the data sources should be given (e.g., different sensor types).

Maintenance Support was cited as the most important requirement. Up to now, it has only been possible to fix acute errors during maintenance work.

Such errors, which only occur temporarily, therefore, fall through the cracks. A historical view of existing data should make these problems visible.

The automatic and permanent checking of components of a facility to *Detect Disruptions* (e.g., a fan fails) and to *Recognise Operating Errors* caused by users (e.g., forget to reset exception schedules for events) have the second highest priority. This enables avoidable excess consumption to be identified and thus supports the process of *Energetic Inspection*. This process is required by law (in Germany) for industrial ACT facilities and is currently performed manually by a technician on site. Here, the current behavior of the system and the wearing parts are checked. In some facilities, a building control system is installed, which can sometimes provide a historical sensor readout if configured accordingly. However, as the employees of the use case company told us, the available data (if any) is usually too incomplete to evaluate the performance of the system.

The requirement *Detect Rule Errors* has priority 3. Incorrect regulations can cause considerable additional consumption that goes unnoticed. For example, the air conditioner and heater may start simultaneously at a certain temperature. The user does not notice this because the room temperature is satisfactory.

Data obtained from the system can bring about further changes in maintenance (priority 4). On the one hand, it is possible to *Dynamically Adjust Maintenance Cycles*. It is better to determine maintenance intervals by the intensity of the use of a facility rather than fixed times. On the other hand, it is possible to detect components with deviation behavior to maintain or replace them before they break (*Predictive Maintenance*).

Furthermore, a few requirements will play a role in the future (priority 5). However, the technical foundations for this are already to be created, at least to some degree, as part of the current project.

Understanding avoidable excess consumption by the system can open up new business models for the company in the future. For example, if an oversized fan is identified, a more suitable one can be installed. This swap would be done free of charge, and the company would share in the electricity savings. *Contracting* in this way is only possible without significant risk if a good data basis is created.

Once sufficient data is available from many facilities, comparisons can be made between them. This is intended to detect, for example, the oversizing of a facility (*Facility Dimensioning*). Often a facility is designed for more people in a room or building than are actually present.

Before a system can be used sensibly and productively, many details must be set and implemented in the control system. Therefore, another requirement is to simplify the process of *Commissioning* and thus save appointments with the customer.

As described above, *Maintenance Support* is the essential requirement of the planned system. Temporary faults, which are caused, for example, by the facility's design, should be made visible with the help of historical data. This results in the data being stored historically in a database. To support this, automatically generated reports and diagrams are to be output. A typical example is that a facility heats and cools simultaneously in strong sunlight. The last maintenance appointment took place in the summer, and the error did not occur then. With the collection of historical data, this event can be detected. Automatically generated reports and diagrams can make this understandable for every user. Among other things, data about humidity, temperature, volume flow, or CO_2 content is needed. The resolution should be one hour, and the recording needs to include at least one spring or autumn, better a year. If possible, permanent storage is preferred. The measurement accuracy depends on the measurement variable. Temperature (+/- 1° C), electrical power (500W), and humidity (5%), for example, need high accuracy. Steps of 10 Pascal, in contrast, are sufficient for pressure.

To *Detect Disruptions* in individual components of an ACT facility, these must always be checked for threshold or experience values to trigger an alarm. Data to be recorded for this purpose and the required measurement accuracy vary for each component. These and similar data can also be used to identify operating errors. By comparing the data with normal values at a certain time, one can inform about this irregular condition. The details of the data required are very similar to those for *Maintenance Support*.

5 LITERATURE REVIEW ON METHOD SUPPORT FOR IoT DEVELOPMENT

This section addresses the question of what work has already been done in MDD of IoT applications, focusing on real-world enterprise use cases. The research approach used, the data collection and the results are described.

5.1 Search Strategy and Process

To systematically identify the existing research about MDD of IoT applications, we performed a Systematic Literature Review (SLR) according to the guidelines of (Kitchenham, 2004). This approach was chosen because it was developed to assess what has already been published on a particular research topic, compare existing research findings, and analyze potential research gaps. Following (Kitchenham, 2004), our research approach was carried out in six steps. We first formulated the general research question:

- **RQ.** What is the state of research on model-driven development of IoT applications?

Next, we conducted the literature review and identified relevant papers. In this way, we developed search strings and defined criteria for inclusion and exclusion in the third step. After extracting and collecting the relevant data from the selected papers in the fourth step, we analyzed these data and summarized the results in section 5.2. Finally, we interpret and discuss the results.

5.1.1 Development of Search Strings

Once the research question was defined, we started the literature review with an initial population and identified ”Model-driven”, ”Enterprise” and ”IoT” as the main keywords. Subsequently, we collected synonyms and associated terms for these:

Table 2: Search terms for the SLR.

Model-driven	Enterprise	IoT
MDD	Company	
MDE	Organization	
MDSD	Business	
(DSL AND Model*)		

The selection of synonyms is based on previous experience in this field. The initial keywords were used to develop several search strings. Synonyms were then added to compare how the results changed. In order to create the search terms, we used the ”Scopus” database. We tested about twenty different search strings, but we only give the most important ones because of the page limitations. For each string, only the titles were scanned initially. Next, we reviewed the abstract and then the introduction and summary. We finally read all selected papers and applied the selection criteria.

In order to complete the literature search, the search strings (see Table 3) were also applied to the databases ”IEEE-Xplore”, ”ACM Digital Library”, ”SpringerLink,” and ”AISeL”. We adapted to the syntax of the respective database. Within the ”SpringerLink” database, we also used the corresponding German translations. Since no other suitable work was found, we decided to retest a version of the search term with additional keywords to see if this had a different effect on the search results than in ”Scopus”. Even so, we did not find any other works with the search term.

The literature review was performed between August and October 2022.

Table 3: Search strings.

Search String	**Number of Results/ Identified Papers**
TITLE-ABS-KEY ((”model driven” OR ”mdd” OR ”mde” OR ”mdsd” OR (”dsl” AND ”model*”)) AND (”enterprise” OR ”company” OR ”business” OR ”organization”) AND (”iot”))	Number of Results: 70 Identified Papers: 6 (Corradini et al., 2022) (Moin et al., 2022) (Nast and Sandkuhl, 2021) (Michael et al., 2019) (Brambilla et al., 2017) (Khaleel et al., 2017)
((((”Full Text & Metadata”:”model driven” OR ”mdd” OR ”mde” OR ”mdsd”) OR (”dsl” AND ”model*”)) AND ”iot” AND (”Full Text & Metadata”: ”enterprise” OR ”company” OR ”business” OR ”organization”)))	Number of Results: 180 Identified Papers: 2 (Ferreira et al., 2018) *(Khaleel et al., 2017)*

5.1.2 Selection of the Papers

For the selection of relevant papers to answer the research question, all abstracts had to be read and the inclusion and exclusion criteria (see Table 4) were applied. We consider a paper relevant if the authors describe a model-based development approach of an IoT application. Moreover, the included approach must be the center of the paper. Papers in which the authors only mention that those approaches can be helpful for certain questions are not relevant to us. Work that is not based on a real company application or has not been evaluated in a company is not considered. We also excluded papers in the context of healthcare, as the requirements are different from ordinary companies.

Table 4: Inclusion and exclusion criteria.

Inclusion Criteria
A model-based development approach of an IoT application is described.
The included approach must be the center of the work (not only mentioned).
Exclusion Criteria
Work that is not based on or has not been evaluated in a real company is not considered.
Work in the context of healthcare is excluded.

Before reading the abstracts, we excluded any items we found that were no papers. In ”Scopus”, 14 of the 70 items had to be filtered out because they are tables of contents, summaries of books, and so on. Two of them were included twice in the results. We then read the abstracts of 54 remaining papers and identified only six relevant papers according to our criteria. If the situation was unclear, we read the entire text to decide whether the text was relevant or not. The second string from Table 3 was applied in ”IEEE XPLORE” (180 results) and added one new relevant paper, resulting in a total of seven relevant texts identified.

5.1.3 Summary of the Search Process

We started this SLR with the population. As a first step, we applied an initial search string to the previously defined literature sources (”IEEE Xplore”, ”ACM Digital Library”, ”SpringerLink” and ”AISeL”).

By adding synonyms to refine the search string, a broader range of research papers could be covered, building the basis for identifying relevant papers. We established criteria to determine which papers were relevant to answering our research questions. Before we started identifying relevant papers, we excluded articles that are, for example, tables of contents, summaries of books, or that appeared more than once in the results. After reading the abstracts, seven relevant papers remained, which are analyzed in section 5.2.

5.2 Search Results

In this section, we answer the research question from section 5.1 using the collected data from the identified relevant papers. First, general information is provided on the research topics, research approaches used, active researchers in the field studied, and the overall activity. Then, the approaches presented in each case are summarized to provide an overview of the current state of research. It continues to examine the extent to which the approaches considered organizational aspects in the development of IoT solutions and what is written about research gaps or problems and criticism. A table was first created in Excel to collect the relevant data from each paper.

5.2.1 Research Activity and Topics

Since our own experience leading up to the SLR has already shown that general MDD approaches tend to focus on technical aspects of IoT solution development, so we did not expect many contributions. Thus, it is not surprising that we found only seven contributions in which the organizational requirements of a real enterprise are considered during development.

We can see in Table 3 that three of the seven relevant papers were written in the last two years (2021-2022). Two were written in 2017, and one each in 2018 and 2019. The seven papers are written by 36 authors, and none appeared more than once. They described approaches with different emphases and at different stages of progress. Four papers are written by authors of the same university (Corradini et al., 2022), (Moin et al., 2022), (Nast and Sandkuhl, 2021) and (Ferreira et al., 2018). The other papers were written in collaboration between two or more universities and different types of organizations or companies.

In summary, it seems that there is no research group which working on this topic for years. This could be because this topic is very practice-oriented and therefore requires applied research rather than basic research projects.

In none of the selected papers is a holistic platform proposed. The use of tools in combination with their own meta-models or modeling languages or a combination of different tools is always described.

5.2.2 Approaches of MDD

(Corradini et al., 2022) propose an approach called FloWare that organizes the modeling and development of IoT applications into distinct steps, manages complexity in representing IoT variability, and enables reusability of design decisions and artifacts. This provides modeling support through functional models to fully represent and handle the potential variability of devices in a given IoT application domain. Once a particular configuration is selected, it is augmented with specific information to automatically derive fragments of IoT applications that the developer within a low-code development environment successively combines. FloWare is fully supported by a toolchain that has been released for public use. A tool was designed to create functional models and a platform including templates that automatically generate the basic application logic for interacting with the selected devices, helping the developer to develop more complex applications. Requirements from a real Smart Campus scenario were taken into account during development.

An open-source research prototype called ML-Square is presented by (Moin et al., 2022). It is based on the Eclipse Modeling Framework and the state-of-the-art in model-driven software engineering literature for intelligent CPS and the IoT. The intended users are mainly software developers who may not have deep knowledge and skills related to heterogeneous IoT platforms and various artificial intelligence technologies, especially machine learning. It provides a domain-specific modeling methodology for its users. Therefore, it enables the automatic generation of source code from the models for the entire software solution of IoT or CPS. The users gain access to the APIs of the libraries and frameworks of machine learning at the modeling level. Using the enhanced software models in ML-Quadrat thus enables the provided model-to-code transformations not only to produce the source code but also the ML models for the target IoT solution and possibly re-train them by observing new data samples later. The approach focuses on Smart IoT services and was initially validated through requirements from four computer science experts (two from industry and two from academia) with different levels of skills in, for example, IoT or Machine Learning. The extended version of this approach, called DriotData, is currently under development and is intended to be offered as a subscription-based service for SMEs. This will include model editors for domain experts without knowledge or skills in the IT area.

The approach described by (Nast and Sandkuhl, 2021), which is integrated with enterprise modeling techniques, considers organizational and technical aspects of IoT application development. A method component for IoT modeling is added to the enterprise modeling language 4EM. The overall objective is methodical and technical support for model-based development of IoT solutions, focusing on organizational integration into business processes, organization structures, and business models. The creation of a model is intended to configure the IoT application and thus provide a basis for data processing without requiring IT skills from the user. The stage of this approach described in the paper is limited to the modeling phase. It contains a meta-model and a DSML for ACT facilities, which were derived based on requirements from an actual use case and interviews with domain experts. Upcoming work needs to extend this to multiple cases and explore the use of the developed models to configure IoT platforms to be used during the operation of the enterprise IoT solution.

(Michael et al., 2019) discuss a way to create IoT systems using a model-based approach to support privacy and data transparency. The relevance and application are shown on a use case from industrial production processes. Tools and frameworks in connection with a set of domain-specific languages (DSLs) are used. A possible DSL model structure, including domain models, a privacy model, and possible instantiations, as well as relevant aspects that must be considered for the system design, are shown. The approach was validated in a real-world production line use case. The realization makes use of two different MDE tools. First, a modeling language development workbench is used that supports agile and compositional development of DSLs. The second tool is a generator for enterprise management, which is based on the first tool and uses a set of models. These are parsed using a templated engine and transformed towards the target, namely output files in the target language. As a result, an information system is created of class diagrams and graphical interface models.

The work of (Ferreira et al., 2018) deals with the complexity of IoT application development for integrating CPS modules into SMEs manufacturing processes. For this purpose, an architecture-based process modeling and simulation of the different phases of existing SME factory production is proposed. This enables real-time information through IoT data collection to feed different production improvement mechanisms (e.g., planning, scheduling, and monitoring). This will be done by providing data on the components in the current environment of SMEs to improve the performance of their production processes. The solution is divided into design time and runtime. At design time, user knowledge leads to a representation of the processes in the factory. There is a tool for creating a model that does not require the permanent support of a specialist. The resulting BPMN diagram is then executed by another tool (after being refined there). An IoT device deployed on a machine enables the coordination of hardware and software components. Information such as the time of completion activities, the number of products manufactured, wasted products, and production or setup times for the machines can be given in real-time. To avoid any complication or waste of time in the production process, an additional tool was developed to be used by the factory workers to check the production schedule or detect component errors. The experiment prototype was validated in a polishing process as part of a real company's production process of cutlery.

(Brambilla et al., 2017) focus on requirements and usage scenarios that cover the front-end aspects of IoT systems. The proposed model-driven approach to design interfaces includes defining specific components and design patterns using a visual modeling language for IoT applications and describing an implementation of the solution that includes automatic code generation from the models. It contains the definition of the main domain-specific concepts for IoT and typical use cases, a visual modeling language focusing on user interaction aspects, and a set of design practices that increase productivity and simplify the design of IoT solutions. Moreover, tools for the design, deployment, and execution phases of IoT applications are implemented. The validation of the approach in three different industrial use cases in cooperation with a company is described.

The Enabling Business-based Internet of Things and Services (ebbits) platform with a focus on the industrial domain is presented from (Khaleel et al., 2017). Heterogeneous applications were deployed and tested, such as a wireless sensor and actuator network for monitoring industrial machinery and an RFID-based system for operator management, locating, and authorization. The latter includes an interactive user interface for wearable devices to visualize real-time information from devices in the physical world. To simplify the process of creating IoT applications, tools for MDD are used. These developments are based on an IoT middleware designed to enable the seamless integration of heterogeneous technologies and processes into traditional enterprise systems. This paper presents the deployment of the prototype in the automotive industry.

5.2.3 Interpretation of the Results

This section completes the SLR and addresses the interpretation of the results. To provide an overview of the current state of the research on MDD of IoT applications, the identified papers are examined in the context of the overarching research question.

The results showed that there is not much research on MDD of IoT applications based on requirements from real-world use cases from enterprises. A small number of papers were identified. However, that addressed the topic in a variety of ways based on the inclusion criteria selected. Only (Corradini et al., 2022), (Nast and Sandkuhl, 2021), and (Ferreira et al., 2018) combined technological and organizational aspects in the development process. The rest of the papers validated their approaches after development in real-world use cases in cooperation with companies.

In fact, the results showed that there are already many different approaches to handling the complexity of IoT application development. Tools containing meta-models and a graphical modeling language are often used in MDD.

Not much is written in the selected papers about further research or problems in this area. (Corradini et al., 2022), (Moin et al., 2022), (Nast and Sandkuhl, 2021), (Michael et al., 2019), and (Brambilla et al., 2017) intend to apply their described approaches in different domains to validate them. A need to improve the application logic and functions and to achieve user-friendliness and thus higher acceptance is identified by (Corradini et al., 2022), (Ferreira et al., 2018), and (Brambilla et al., 2017). (Khaleel et al., 2017) merely summarizes the results and does not provide an outlook on further action.

The work reviewed in this chapter provides promising approaches that focus on the technological aspects of model-driven IoT application development (at different maturity levels). Usability plays an important role in all approaches, to a greater or lesser extent. (Moin et al., 2022) and (Nast and Sandkuhl, 2021) even explicitly target users without special IT skills and thus non-IT SMEs. In summary, there is no validated method that combines technological and organizational aspects in all phases of the development process, and there is no specific support for SMEs.

6 TOWARDS METHODICAL/TECHNICAL SUPPORT

After describing the requirements for the overall application resulting from the use case in section 4.2, section 6.1 now presents the requirements that relate directly to the methodological/technical support. Section 6.2 presents the initial version of methodical/technical development support for SMEs.

6.1 Requirements

ACT facilities for the industry are not mass-produced but designed individually for each customer. In these systems, many components have to work together, and we need a variety of sensors to understand what is going on inside them. However, the signals from these sensors are not readily interpretable. Often, they only measure an analog signal of 0 to 10 volts, which must be converted into a physical unit of measurement. To make sense of these measurement points and understand the performance of the system, they must then be processed and put into context. As the configurations of these air conditioning systems vary, so does the arrangement of the measurements. Only some systems have a cooling unit, and some use it only for cooling, while others also use it for dehumidifying. These heterogeneous structures also have an impact on the IT architecture. On the one hand, the systems are heterogeneous in their configurations, and the data must be preprocessed at great expense to be usable. On the other hand, there is great potential in comparing systems with similar configurations. At the same time, the implemented system must be usable by climate experts. Emphasis is placed on a system that does not require a lot of IoT and analysis-specific knowledge but is usable by the end user.

While the requirements described in section 4.2 relate primarily to the data and, thus, to the overall system, it was possible to derive further requirements in the various development phases. The use of a method for the development of IoT applications must be usable without requiring knowledge of IT or data processing. For this purpose, appropriate interfaces must be provided for configuration and later also for operation and maintenance. Therefore, for configuration, options are created that require only domain-specific knowledge. In addition, a kind of vocabulary for the designation of sensors or their IDs and clear definitions of the configuration data (unit of measurement, data format, or range of values) must be defined. Another requirement is that ACT facilities can be visualized. On the one hand, this helps ACT technicians in designing the solution. On the other hand, these visualizations can be used for presentations to customers to explain repair measures or the replacement of components in an understandable way. The monitoring of ACT systems must be made possible, for example, through alarms or comprehensible diagrams and data evaluations.

6.2 Initial Method Structure and Tool Architecture

We developed a tool that includes a meta-model and a DSML for ACT facilities to support the ACT technicians in designing the IoT solution. The tool was developed using the ADOxx meta-modeling platform. This is a development and configuration platform for the implementation of modeling methods. Using this platform, it is possible to realize a full-fledged modeling software that contains procedures and functionalities in the form of mechanisms and algorithms in addition to the modeling language.

The modeling language for ACT facilities is based on the requirements of the case study. An example model of a fictitious facility containing some of the modeling objects is shown in Figure 2.

The classes of the meta-model represent the possible components in such facilities. The attributes contain, e.g., information about the type of the components or the unique identifiers of the sensors. The symbols are based on the European standard DIN EN 12792 and the knowledge of the domain experts involved in the project. The graphical representation, as well as the designation of the components, depends on the entered attributes. Arrows show the logical relationship between the components and the airflow direction. Sensors are represented with a circle and a line to the component or location in the model. The letters in the circle indicate the sensor type. An example model of a real facility (see Figure 1) shows some of the objects in the modeling language and contains eight sensors: two each for controlling the supply and exhaust air (temperature in °C and CO_2 content in ppm). Furthermore, the two air filters are equipped with a sensor for the pressure difference (unit of measurement: Pascal), and the fans with a sensor for the volume flow (unit of measurement: m³/h).

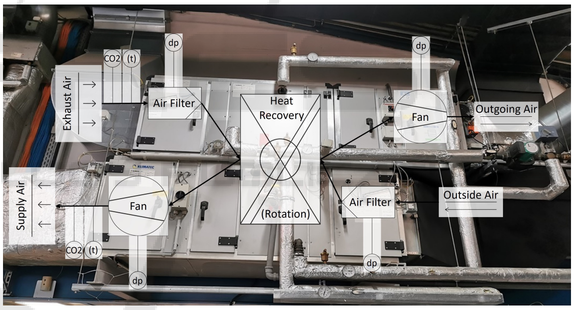

Figure 1: Model of the example facility.

The creation of a new facility in the tool is started with the input of configuration data. Required information about the location, the operator and owner, and the components of a facility, are requested via dialog boxes. The input of these values automatically generates the corresponding modeling objects, including the attribute values (e.g., fan size). Unique IDs are assigned to the sensors, depending on their type and position.

The configuration data and the sensors' IDs are converted into a JSON file and sent to a server application using an HTTP request (see Figure 3). This information can also be exported as documentation of the facility and used for presentation or internal purposes of the case study company. For instance, this documentation can help the customer understand his facility, the results of energetic inspections, or even the need for renewal and repairs.

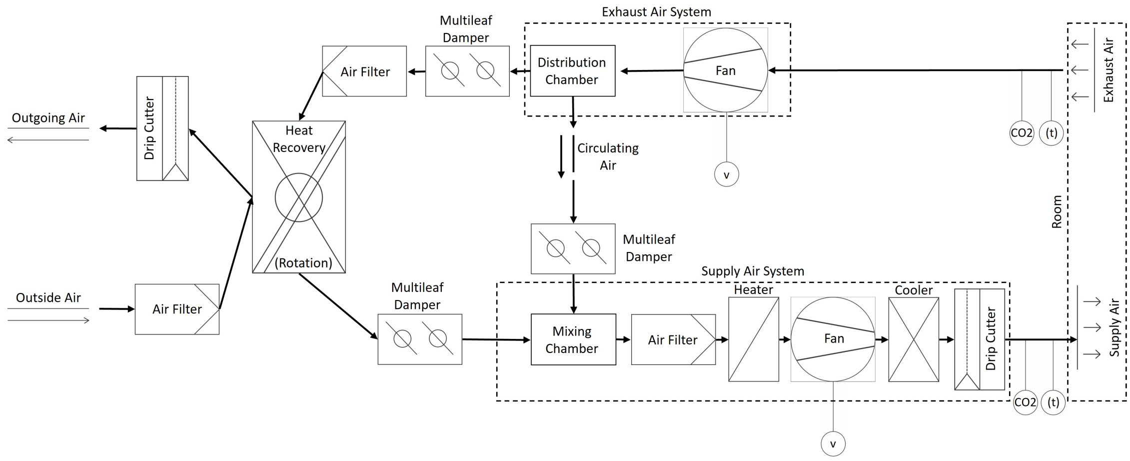

Figure 2: Objects of the DSML.

The developed tool allows the technician to configure the installed sensors. Parts of the physical configuration are covered by collecting hardware-related sensor information and mappings to measured aspects. The configuration enables the data processing of the logical part by indicating what type of ACT facility is present. The user of the tool does not need specific knowledge or skills in IoT and data analysis.

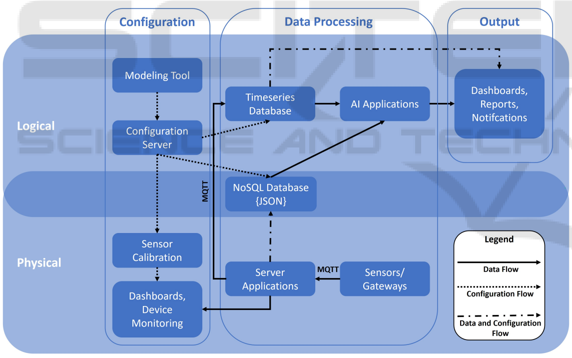

Figure 3: Architecture of the overall system.

7 SUMMARY AND FUTURE WORK

Starting from requirements to methodical/technical support for IoT implementation in an industrial use case, this paper investigated how SMEs can be supported in developing and introducing IoT solutions that integrate business (i.e., business model and organizational integration) and IT aspects (i.e., software and systems engineering). The initial structure for method support and a first architecture of tool support for this method was proposed. The work was also anchored on a systematic literature analysis in the field.

The successful application of the method and tool support in the case company shows that it meets the requirements of at least this specific SME. The method and tool support also address the situation in SMEs when it comes to resource, cognitive, and IT readiness: clearly defined method steps and free-of-charge tool support contribute to low resource requirements. The modeling tool and the possibility to generate part of the configuration reduce the need for special employee training and lower the cognitive readiness threshold. The use of standardized components minimizes IT readiness expectations as much as reasonable. The other readiness aspects require more investigation in future work.

The main limitation of our work is that we base the requirements for the method support on only one use case. This poses the threat of having tailored the method proposal to the demand of the use case enterprise only. However, the results of the literature analysis and similarities to established methods give reasons to believe that the method might be transferable.

The future work will have conceptual and empirical nature. From a conceptual perspective, a more detailed description of the method and architecture and the extension of the tool support is required. From an empirical perspective, more case studies are necessary to ensure validity. Furthermore, evaluation with stakeholders in SMEs is needed.

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