

A framework for creating an IoT system specification with ChatGPT

Mario Binder, Vitaliy Mezhuhev^{*}

Institute of Industrial Management, University of Applied Sciences FH JOANNEUM, Austria

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ABSTRACT

The Internet of Things (IoT) is a core concern for the digital transformation of the industry. However, the development of IoT systems, starting from creating specifications, is a serious and time-consuming effort, which requires high levels of expertise. This paper introduces a novel approach leveraging large language models, specifically ChatGPT, to streamline the generation of IoT system specifications from initial, unstructured customer requirements. A framework, adapting the ISO IEC/IEEE 12,207:2017 standard, is developed for this purpose. The utility of this framework is validated through the development and expert evaluation of a specification for a campus laboratory IoT use case. The findings demonstrate ChatGPT's effectiveness in producing specifications that are understandable, complete, and unambiguous, thus offering a substantial aid to the industry in overcoming the complexities of IoT system specification development. At the same time, the study identified specific tasks within the requirements engineering process for IoT systems that ChatGPT could not effectively perform, such as verification, obtaining agreements, and maintaining traceability of requirements between stakeholders. The findings offer valuable insights into the practical applications of AI in the domain of IoT development, particularly in automating the specification generation process. These contributions not only advance the understanding of AI's role in IoT development but also open pathways for further research on refining AI-assisted methodologies for system specification and beyond.

Introduction

Industrial Internet of Things (IIoT) and Internet of Things (IoT) are commonly used in the context of Industry 4.0, which concerns the digital transformation of the industry, representing the fourth industrial revolution [4,5]. The term Industry 4.0 was proposed in 2011 by the German Federal Government as part of their Hightech Strategy 2020 [7]. It is a government program that aims to improve German innovation abilities to increase its global competitiveness, by consolidating innovation activities and resources in the sectors of energy and climate, health and nutrition, security and communication and mobility. While the first three industrial revolutions are characterized by being driven by the utilization of mechanical production, powered by water and steam, the introduction of division-based mass production powered by electrical energy, the application of electronics and IT to realize the automation of production, the fourth industrial revolution is driven by the implementation and utilization of Cyber-Physical Systems (CPS) [13]. The goal of Industry 4.0 is to empower the German business to realize the four characteristics: a high level of product individualization, flexibilization and efficient production of lot size one, deeper integration of customers and partners, and combining production with

^{*} Corresponding author.

E-mail address: vitaliy.mezhuhev@fh-joanneum.at (V. Mezhuhev).

services [14,19].

The term IoT was first used in 1999 by Kelvin Ashton and since that, it has been applied to connected devices in consumer, domestic, business, and industrial settings. There are numerous definitions of IoT, IIoT, and related topics that are often used interchangeably like the above-described Industry 4.0. A more recent definition of IIoT stems from an analysis by Boyes et al. in their paper, in which they describe IIoT as: *“the use of certain IoT technologies – certain kinds of smart objects within cyber-physical systems – in an industrial setting, for the promotion of goals distinctive to industry”* [4].

What differentiates IIoT from IoT is the concern for industrial applications, such as energy management and manufacturing, by the application of interconnected sensors, actors, tools, and any other kind of device fitted with computational and connection capabilities [9]. In this sense, IIoT characterized the specific application of IoT for the industry, enabling wirelessly connected manufacturing systems that control and make meaningful conclusions on their own [4,12].

IIoT systems enable integration and connection of software engineering with enterprise systems, business processes, and analytics, to create transparency, flexibility and to support decision-makers. However, there are limited models and techniques to define IoT system architectures in a structured way [15]. This challenge is a serious obstacle to the wider adoption of IoT technologies. Only a few approaches have been proposed for IoT and IIoT systems design, with many of them being time-consuming, requiring a high level of expertise, or lacking separation of concerns and high-level abstraction to address heterogeneity and the large scale of such systems. Numerous approaches have been proposed in the closely associated domains of ubiquitous computing, wireless sensor networking, pervasive computing, and software engineering to address the above-mentioned challenges, but these approaches cover only limited parts of these challenges when applied to IoT [17].

The difficulty of defining IoT architectures and system specifications is varied; on the one hand, many stakeholders are involved, deciding, and contributing, while using different tools and methods familiar to them. On the other hand, the heterogeneity of IoT technologies, commonly containing a variety of platforms, protocols, and languages hinders communication, thus causing problems with the interoperability of the system. To handle these obstacles, many companies are currently required to involve more human resources with highly specific expertise. Companies that are unable to provide resources and personnel in the required quantities may end up with flawed applications that can be exploited for network attacks [3].

This study aims to ease the difficulties of creating IoT system specifications through the application of the AI-based transformer model ChatGPT [1]. The goal of this study is to develop a framework to transform unstructured requirements from non-experts into IoT system specifications. Concerning the research problem, the following research questions are addressed:

RQ1. *How can ChatGPT be utilized to create IoT system specifications?*

RQ2. *What is the quality of the generated IoT specification?*

To answer RQ1, a framework for creating an IoT system specification is established based on the work of [20], those who created a tailored and harmonized process for the requirement engineering of IoT systems based on the ISO/IEC/IEEE 12207:2017 [11]. This process is modified to adhere to the limitations of ChatGPT to create a structured process that links the individual items of content for the creation of a specification, based on initial customer requirements.

To validate the framework, a specification for a campus laboratory use case is generated and presented to experts for evaluation within a survey. In this survey, experts assessed the specification's quality and content based on a questionnaire, including specific quality and content criteria, like specification's understandability, completeness, unambiguity, and suitability concerning the initial customer requirements. Furthermore, the generated specification was compared to the real, implemented system, to determine differences and similarities. Finally, the findings are summarized, and a conclusion is drawn.

The paper is structured as follows. Chapter two details the methodology of developing the framework including the steps involved in creating an IoT specification for a use case. Chapter three describes the validation of the framework, the survey, and its results as well as the comparison of the specification and the real, implemented system. Chapter four discusses the findings and chapter five summarizes the results and draws a conclusion on this study.

Methodology

The ISO IEC/IEEE 12207:2017 standard outlines the processes for software and systems engineering throughout the software life cycle. This standard was tailored by Silva et al. to fit IoT systems and in this research, it was used as the foundation for the development of the process model (ISO/IEC/IEEE 12207:2017[11]).

Framework description

To begin with the proposed process model (Fig. 1), the customer requirements are to be derived. This provides the context to the first ChatGPT prompt to define the problem or opportunity, the resulting output of which was next used to provide context to the prompts for the stakeholder identification as well as the analysis of the problem or opportunity. The identified stakeholders are then used to identify their needs and transform them into requirements. The outcomes of the problem or opportunity analysis are then further detailed. The results of both processes are used to contextualize the prompt to let ChatGPT create an IoT solution, based on which, scenarios are generated. The IoT scenarios are then used to identify IoT system components and actions, both of which are needed to specify the device and software components. Finally, the use cases are described, based on the context provided by the specified device and software components as well as the previously defined IoT scenarios. The items of content marked with blue backgrounds and linked with blue arrows are consolidated into the IoT specification. Finally, results are formatted, without changing the wording of the content, to improve the readability of the specification. A sample of the resulting specification can be found in the appendix.

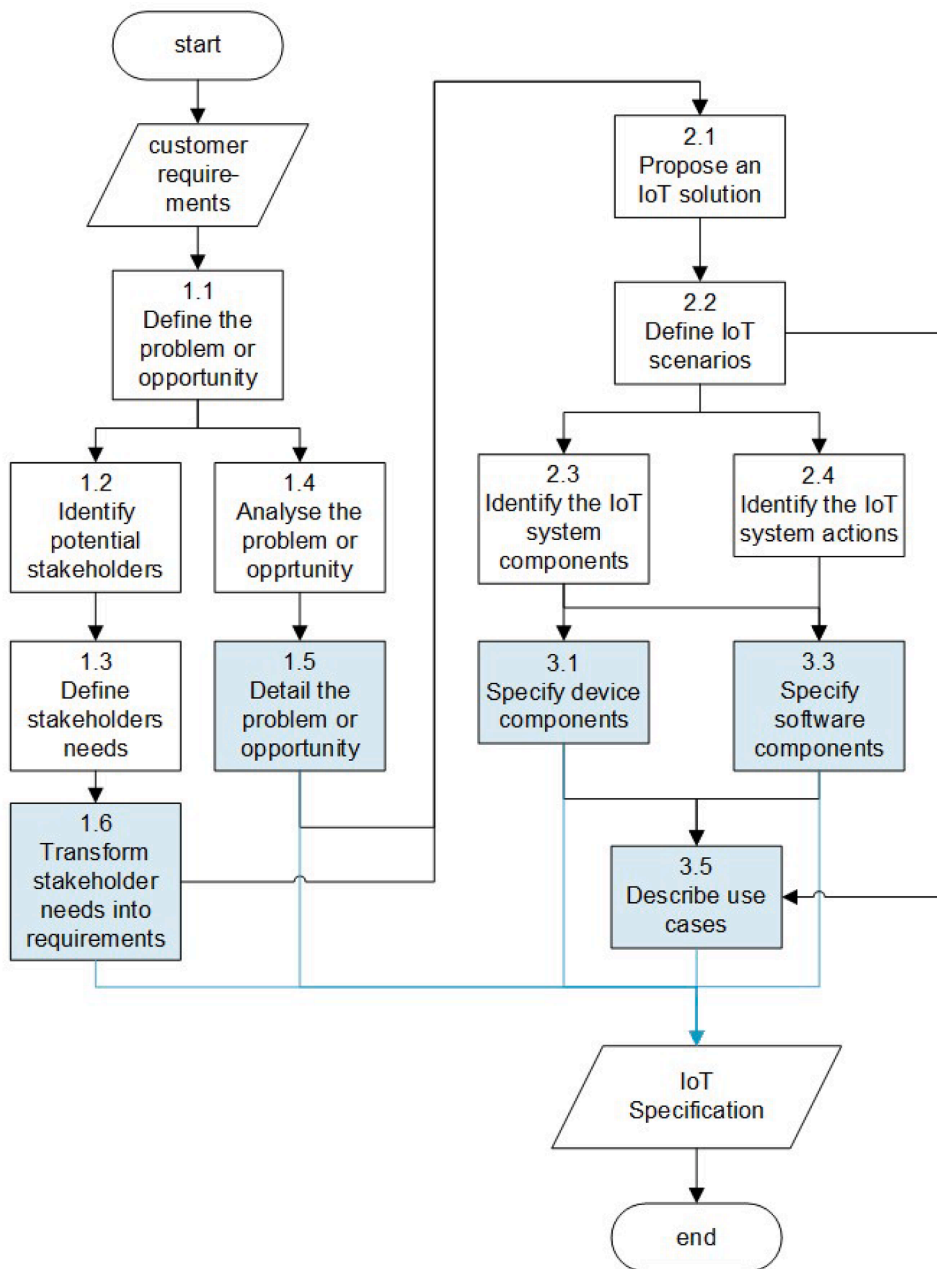


Fig. 1. Framework for the generation of the IoT systems specification with ChatGPT.

Prompt design

The following sub-chapters outline the process of using a proposed framework for ChatGPT prompts contextualization, describing how the outputs of the individual tasks are used as further ChatGPT inputs to create the final specification. Furthermore, limitations experienced during testing are outlined and incorporated into the design of the final framework. All content was generated with ChatGPT of July 6 Version, based on GPT-3.5 on 27.07.2023.

ChatGPT itself lists many potential applications if asked how it could support the requirement engineering process of creating an IoT specification. However, to create a specification that does not consist of general text, the context needs to be provided with the input prompt.

The prompts were designed based on the tasks of the sub-processes of the proposed framework. In addition, the name of the sub-process and a number to identify the task were added to provide structure and ease of navigation in the ChatGPT chat:

[number] [task description] As part of the [sub-process] for an IoT System based on the following context: [context]

Applying this structure to the tasks listed in the RE process yields the following prompts: [Tables 1–3](#).

Case study

Initial requirements were derived from the paper of Poongothai et al. “Design and Implementation of IoT Based Smart Laboratory”. The goal of the implementation was to automate the control of the laboratory’s energy-consuming devices, including projectors, lighting, and air conditioning [18]. The following text was extracted from the paper and is used as the initial context for ChatGPT:

“As the campus grows every year, new management problems and energy issues appear. Managing the resources in the campus has become a real problem. Monitoring and controlling the unused devices that consume power during human absence is also a major inability. In addition to this, coordinating the people participating in the daily activities of the laboratory is tedious when the population of the usage of the space outnumbers a manageable threshold. Another problem is power management. It is difficult to monitor all sub-systems such as lighting, projecting and air conditioning systems. But if these are left indiscriminately, energy will be wasted. People cannot check the status of the sub-system at ease.” [18]

Presented in [Fig. 1](#) framework was used for contextualization of the ChatGPT prompts (use the output of the individual steps to

Table 1

ChatGPT prompts for project scope definition.

- 1.1 Define the problem or opportunity, which involves the analysis of the problem or opportunity to understand its scope and the definition of its context and parameters.
- 1.2 Identify potential stakeholders, that is, people who have an interest in the IoT system.
- 1.3 Define stakeholder needs, which include the identification of the context of the use of the IoT system, the elicitation of stakeholder needs, prioritization of the elicited needs, and the elaboration of the final list of stakeholder needs.
- 1.4 Analyze the problem or opportunity and stakeholder needs to decide if there is a sufficient understanding to evaluate if the construction of an IoT system is feasible and desirable or if there is a need for more information.
- 1.5 Detail the problem or opportunity. If the construction of the IoT system is approved as a project, this activity is performed to produce a more detailed definition of the problem or opportunity.
- 1.6 Transform stakeholder needs into stakeholder requirements, which include the identification of requirements, functions, constraints, and quality characteristics.
- 1.7 Analyze stakeholder requirements to evaluate, among other criteria, if the requirements are necessary, complete, unambiguous, feasible, verifiable, and affordable.
- 1.8 Obtain explicit agreement about requirements from stakeholders, which means that a common understanding of the IoT system has been achieved.

Table 2

ChatGPT prompts for IoT system definition.

- 2.1 Propose an IoT solution, based on stakeholder requirements and the detailed definition of the problem or opportunity.
- 2.2 Define IoT scenarios. IoT scenarios should be defined in narrative form to communicate the system’s behavior in such a way that stakeholders from different areas and levels of knowledge could understand and contribute to the discussion.
- 2.3 Identify the IoT system components. Based on the scenario definition the components of the IoT system are identified (sensors, actuators, tag readers, software systems, smartphones, wearable, among others).
- 2.4 Identify the IoT system actions. In parallel with the identification of the components, the actions performed by these components should be identified and described aiming to capture the system’s behavior and interaction between components.
- 2.5 Identify alternative arrangements composition. IoT Interaction Arrangements represent the interaction flow among devices and other components. Silva et al. [20] has defined nine IoT Interaction Arrangements to represent recurrent interaction flows. An IoT system may implement one of these arrangements or a composition of some of them. As a result of this activity, one or more alternative arrangements are identified.
- 2.6 Evaluate alternative arrangements composition. This activity aims to evaluate the alternative composition, identified in the previous activity to decide on the most suitable for the specific IoT system.

Table 3

ChatGPT prompts for IoT system requirements definition.

- 3.1 Specify device components. This activity aims to produce a detailed specification of the devices that compose the IoT System.
- 3.2 Verify the specification of device components. This activity aims to evaluate the specification of the device components of the IoT System to determine if they address the system’s needs. The verification implies the resolution of all non-conformities.
- 3.3 Specify software components. This activity aims to produce a specification for each software component, which includes functional, nonfunctional, and interface requirements.
- 3.4 Verify the specification of software components to confirm that the software requirements specification is correct, comprehensible, consistent, and possible to implement and test. This activity includes the resolution of all non-conformities identified.
- 3.5 Describe Use Cases. This activity aims to produce a description of each scenario, which includes a detailed description of the interaction flow among components, the alternative, and exception flows. The use case description includes the description of the business rules.
- 3.6 Verify Use Case descriptions to confirm that they are correct, comprehensible, and consistent. This activity includes the resolution of all non-conformities identified.
- 3.7 Establish and maintain traceability between stakeholders’ requirements and system/software requirements. Traceability allows verifying that one or more of the IoT system requirements meet the stakeholders’ requirements.

provide specific context for the next steps). It was important to perform the whole process in one session of the ChatGPT 3.5, as a change results in the loss of the context. For example, when ChatGPT was asked to propose an IoT solution for a problem without specification of the context, ChatGPT generated the use case scenario for the management of a gym.

Table 4 shows a sample of successful identification of potential stakeholders, based on the prompts contextualizing.

Experiments showed that ChatGPT is not able to provide meaningful responses for tasks such as verification (tasks 3.1, 3.3, 3.5), obtaining agreements (task 1.8), and maintaining traceability of requirements between stakeholders (3.6). This is why these steps were excluded from the proposed framework.

For this use case, establishing and maintaining traceability between the stakeholders' requirements was not in the scope. The steps involving alternative arrangement compositions, based on the described by Siva et al. IoT interactions were also not performed. While these steps are important for identifying and evaluating alternative solutions, this would require ChatGPT to make a decision, which is outside of its possibilities [6].

Based on these restrictions, the process from Silva et al. was adapted, yielding the structure that shows the linking of outputs to prompts for contextualization, as displayed in Fig. 1. This process can be performed by ChatGPT without intervention or adjustments concerning the generated specification content. The blue lines indicate the items of content that end up in the final specification, all other items are intermediate outputs.

Validation

Two methods were used to validate the framework and thus the applicability of ChatGPT for creating IoT specifications. A survey was conducted among experts to determine the quality of the generated content and to assess the suitability and feasibility of the specification. Secondly, the specification was compared to the real, implemented system, to determine similarities and differences.

Survey

In the survey, the generated IoT specification for the campus laboratory was presented to the experts. A questionnaire was used to evaluate the quality and content of the generated specification. The participants were selected based on random sampling from authors of peer-reviewed articles concerning IoT topics.

The experts were contacted via e-mail, including a description of the motivation and goal of the study, a link to the survey, and a sample of generated by ChatGPT specification. In total, 3685 experts were contacted to participate in the survey, and a gentle reminder was sent after a week. In total, 3685 experts were contacted, and 40 volunteered, which concludes a response rate of 1,09 %.

Evaluation criteria

The evaluation of the specification encompasses an overall examination of both its quality and content, evaluating two key perspectives. The first perspective focuses on specification clarity, completeness, and comprehensibility [8]. The second perspective assesses the feasibility and suitability of the content of the specification for its intended use (ISO/ IEC/IEEE 15288:2023, 2023) [10]. Based on these criteria, a Google Doc survey was developed.

Evaluation of quality

The quality of the specification was evaluated based on the criteria defined in the NLSRS Quality Model created by Fabbrini et al. They developed a framework that defines two high-level goal properties to assess the quality of a specification, based on the requirement sentence and document quality. Next, Fabbrini et al. decompose them down into sub-properties, which are used as evaluation criteria for this study [8]:

- **Non-Ambiguity:** Non-Ambiguity describes the capability of a requirement to have a unique interpretation. Indicators for ambiguity are implicit subject sentences, optional phrases, subjective vague, and weak sentences.
- **Completeness:** Completeness defines the capability of the specification to avoid discrepancies and to reference precisely identified entities. Indicators are incomplete sentences or sentences missing clear references, making it difficult to reference the requirement to its belonging system component.
- **Understandability:** Understandability describes the capability of the specification to be fully understood when read, in the context of the system. Indicators are the number of sentences used to describe a requirement, the length of sentences, the number of words per sentence, and the usage of acronyms that are not completely explained in the document itself.

Evaluation of content

The content was evaluated based on the validation process described in the (ISO/ IEC/IEEE 15,288:2023, 2023), the goal of which is to determine if the specified requirements ensure that the "right solution is built". Therefore, the specification was evaluated in terms of feasibility and usefulness to assess if the proposed system could be implemented and would serve the business or mission objectives and fulfill the stakeholders' needs.

- **Feasibility:** It defines if the created system could be implemented and would work as intended, as outlined in the specification.
- **Suitability:** It defines how fitting the designed solution is for the intended business case, fulfilling the desires and needs of the stakeholders and reaching mission objectives.

Table 4

Prompt & response with contextualization.

Prompt

1.3 Define stakeholder needs, which include the identification of the context of the use of the IoT system, the elicitation of stakeholder needs, prioritization of the elicited needs and the elaboration of the final list of stakeholder needs. As part of the Project Scope Definition sub-process for an IoT System based on the following context:

Potential stakeholders for the IoT system in the given context may include:

1. Campus Administration: The administration team is responsible for overall campus management and would have a keen interest in improving resource management, addressing energy issues, and enhancing coordination of activities.
2. Facilities Management: The facilities management team oversees the maintenance and operation of campus infrastructure, including lighting, HVAC systems, and other subsystems. They would benefit from an IoT system that provides real-time monitoring and control capabilities.
3. Energy Management Department: The department responsible for energy management would be interested in implementing an IoT system to improve power management, reduce energy wastage, and optimize energy consumption in the campus.
4. IT Department: The IT department plays a crucial role in deploying and maintaining the IoT system infrastructure, including network connectivity, data storage, and security. They would have a stake in ensuring the system's reliability and integration with existing IT infrastructure.
5. Campus Users (Faculty, Staff, Students): The individuals using the campus facilities would benefit from the IoT system by having better control over subsystems, such as adjusting lighting and temperature settings, and being able to check the status of devices easily. This convenience and improved user experience would enhance their productivity and comfort.
6. Sustainability Initiatives: Stakeholders involved in sustainability initiatives within the campus would have an interest in reducing energy consumption, improving resource management, and achieving environmental goals. The IoT system can support these initiatives by providing data-driven insights for sustainable decision-making.
7. Maintenance and Support Teams: Teams responsible for maintaining and supporting the IoT system would be stakeholders in terms of ensuring its proper functioning, troubleshooting any issues, and providing timely support to users.
8. Regulatory Authorities: Depending on the campus's location and applicable regulations, regulatory authorities may have an interest in ensuring compliance with energy efficiency standards, environmental regulations, and data privacy requirements related to the IoT system.

It is important to conduct a comprehensive stakeholder analysis to identify all relevant stakeholders specific to the campus and involve them throughout the project to gather requirements, address concerns, and ensure the successful implementation and adoption of the IoT system.

Response

Based on the identified potential stakeholders, the following stakeholder needs can be elicited: 1. Campus Administration:

- Improved resource management to optimize resource allocation.
- Enhanced coordination of activities to streamline campus operations.
- Real-time visibility into resource utilization and energy consumption.
- Data-driven insights for informed decision-making.

2. Facilities Management:

- Real-time monitoring and control of campus infrastructure subsystems.
- Proactive maintenance alerts and notifications.
- Energy efficiency optimization for lighting, HVAC, and other systems.
- Integration of the IoT system with existing facilities management processes.

3. Energy Management Department:

- Efficient power management and reduction of energy wastage.
- Real-time monitoring and reporting of energy consumption.
- Optimization of energy distribution and usage.
- Integration with energy management systems and protocols.

4. IT Department:

- Reliable and secure IoT system infrastructure.
- Seamless integration with existing IT infrastructure.
- Scalability and flexibility of the IoT system.
- Data storage, management, and analytics capabilities.

5. Campus Users (Faculty, Staff, Students):

- Convenient control and access to subsystems (e.g., lighting, temperature).
- Real-time information on device status and availability.
- User-friendly interfaces and intuitive interactions.
- Personalized settings and preferences for comfort and productivity.

6. Sustainability Initiatives:

- Support for energy-efficient practices and sustainability goals.
- Data-driven insights for measuring and improving environmental impact.
- Integration with sustainability reporting and certification systems.
- Ability to identify areas of improvement and track progress.

7. Maintenance and Support Teams:

- Effective monitoring and diagnostics for quick issue resolution.
- Remote troubleshooting capabilities.
- System maintenance and upgrade notifications.
- Documentation and training resources for support personnel.

(continued on next page)

Table 4 (continued)

Prompt
8. Regulatory Authorities:
<ul style="list-style-type: none"> - Compliance with energy efficiency and environmental regulations. - Data privacy and security measures. - Transparency in data collection and usage. - Documentation and reporting features to meet regulatory requirements.
These needs should be prioritized based on their criticality, impact on stakeholders, and alignment with the overall goals and objectives of the IoT system implementation in the campus context.

Based on these criteria, a survey was developed, allowing for individual evaluation of each chapter in the generated specification based on an ordinal scale with five levels. The content of each chapter was evaluated by asking experts for suitability concerning the initial customer requirements, providing the participants with a scale ranging from strongly agree to strongly disagree. After content evaluation, an optional question was asked for recommendations for changes, allowing participants to provide additional input. The quality was evaluated with three separate scales for understandability, completeness, and unambiguity.

After evaluation of the content and quality of each chapter, the feasibility and suitability of the specification were evaluated, by a five-point scale ranging from feasible to not feasible, and from suitable to not suitable, respectively. Participants were required to recommend changes to make the proposed approach more feasible and more suitable.

Survey results

The chapter presents the analysis of results, including the optional recommendations, provided by experts for each chapter. Figures visualizing the frequency of each answer and detailed numbers, percentages, and the median are given in the tables below. Lastly, the confidence intervals, for a positive outcome of each survey statement, are presented, displaying the lower and upper confidence levels for the total population of IoT experts. For the calculation of the confidence intervals, the Wilson formula (1) was used, as it is better suited for smaller sample sizes [2].

$$P = \frac{h + \frac{k^2}{2n} \pm \frac{k}{\sqrt{n}} \sqrt{h(1-h) + \frac{k^2}{4n}}}{1 + \frac{k^2}{n}} \quad (1)$$

In the formula (1), the number of responses is represented by n , and the proportion of positive answers, to which strongly agree and agree are counted, is represented by h . The coefficient k is 1.96 which corresponds to confidence intervals of 95 %.

Project problem and opportunity

Many participants strongly agreed or agreed, that the generated problem and opportunity description are fitting to the initial requirements, with the median being “agree”. One participant noted that some systems and algorithms might be more suitable for the task of generating IoT specifications. Other recommendations included reducing the scope of the system and being more human-centric. Concerning the quality of the project problem and opportunity description, the majority of participants agreed that the generated content is understandable, complete, and unambiguous.

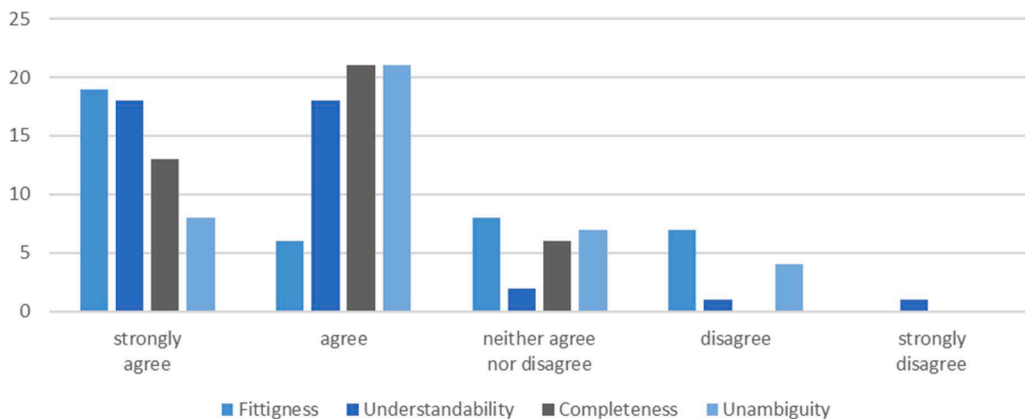


Fig. 2. Survey results – project problem and opportunity.

Table 5

Survey results – problem and opportunity description.

Survey results: problem and opportunity description	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
The generated project problem and opportunity description is fitting to the initial requirements.	19 (47.5 %)	6 (15 %)	8 (20 %)	7 (17.5 %)		2
Are the Project problem and opportunity described understandably?	18 (45 %)	18 (45 %)	2 (5 %)	1 (2.5 %)	1 (2.5 %)	2
Are the Project problem and opportunity described completely?	13 (32.5 %)	21 (52.5 %)	6 (15 %)			2
Are the Project problem and opportunity described unambiguously?	8 (20 %)	21 (52.5 %)	7 (17.5 %)	4 (10 %)		2

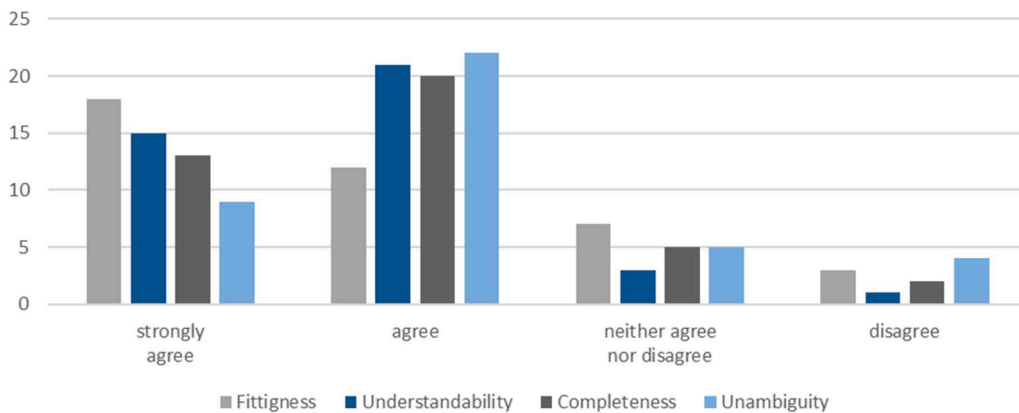
Table 6

Problem and opportunity description – confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
The generated project problem and opportunity description is fitting to the initial requirements.	40	25	63 %	[0.76; 0.47]
Are the Project problem and opportunity described understandably?	40	36	90 %	[0.96; 0.77]
Are the Project problem and opportunity described completely?	40	34	85 %	[0.93; 0.71]
Are the Project problem and opportunity described unambiguous?	40	29	73 %	[0.84; 0.57]

Evaluation of stakeholder requirements

The majority of participants deemed the identified stakeholders as fitting the initial requirements, with the median being “agree”. One expert recommended that vendors and suppliers should be excluded from the stakeholders. The quality of the generated stakeholder requirements was assessed with a median of two, corresponding to agree, for understandability, completeness, and unambiguity.

**Fig. 3.** Survey results – stakeholder requirements.**Table 7**

Survey results – stakeholder requirements.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
The identified stakeholders are fitting to the initial requirement.	18 (45 %)	12 (30 %)	7 (17.5 %)	3 (7.5 %)		2
Are the functional and quality characteristics of the described requirements understandable?	15 (37.5 %)	21 (52.5 %)	3 (7.5 %)	1 (2.5 %)		2
Are the functional and quality characteristics of the described requirements complete?	13 (32.5 %)	20 (50 %)	5 (12.5 %)	2 (5 %)		2
Are the functional and quality characteristics of the described requirements unambiguous?	9 (22.5 %)	22 (55 %)	5 (12.5 %)	4 (10 %)		2

Table 8
Stakeholder requirements – confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
The identified stakeholders are fitting to the initial requirement.	40	30	75 %	[86; 60]
Are the functional and quality characteristics of the described requirements understandable?	40	36	90 %	[96; 77]
Are the functional and quality characteristics of the described requirements complete?	40	33	83 %	[91; 68]
Are the functional and quality characteristics of the described requirements unambiguous?	40	31	78 %	[88; 62]

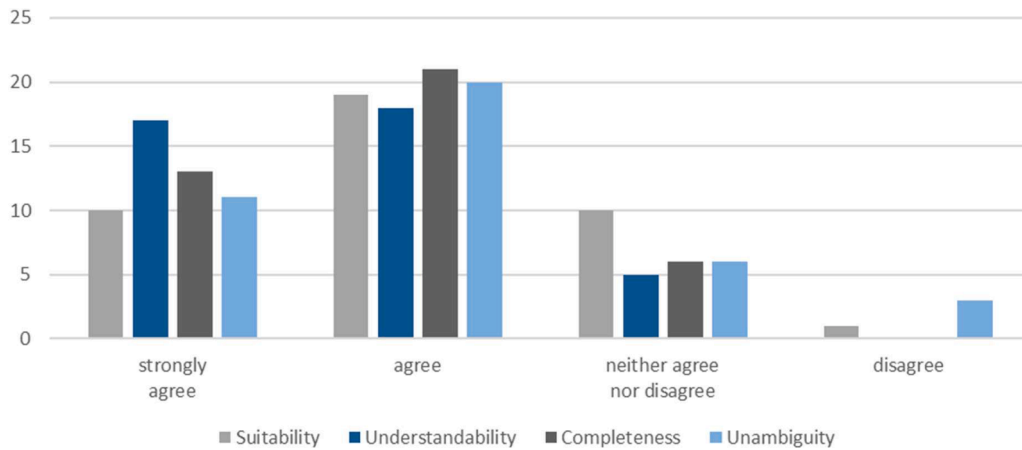


Fig. 4. Survey results – device component specification.

Table 9
Survey results – suitability of device component description.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
Are the specified device components clearly defined, meaning their description is unambiguous?	10 (25 %)	19 (47.5 %)	10 (25 %)	1 (2.5 %)		2
The defined device components are suitable.	17 (42.5 %)	18 (45 %)	5 (12.5 %)			2
Are the specified device components clearly defined, meaning their description is understandable?	13 (32.5 %)	21 (52.5 %)	6 (15 %)			2
Are the specified device components clearly defined, meaning their description is complete?	11 (27.5 %)	20 (50 %)	6 (15 %)	3 (7.5 %)		2

Evaluation of device component specification

Most participants strongly agreed or agreed that the defined device components are suitable. The experts recommended improving the granularity of the specification, especially about the devices that should be integrated and to improve it the technical details concerning communication topology and protocols. Furthermore, one expert recommended simplifying the system by removing some components to save costs. The participants majorly agreed that the device component specification is understandable, complete, and unambiguous.

Evaluation of software component specification

With a median value of “agree”, the software component description is rated as suitable by most participants. Participants noted that the integration with the management platform is not adequately addressed in the content of the specification and that more information about communication protocols and dataset curation tools would improve the specification. Concerning the quality of the software component specification, most participants agreed or strongly agreed that it is understandable, complete, and unambiguous.

Evaluation of described use cases

The majorly agreed or strongly agreed that the presented use cases are suitable, based on the initial requirements, with a resulting

Table 10
Suitability of device component description - confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
Are the specified device components clearly defined, meaning their description is unambiguous?	40	29	73 %	[84; 57]
The defined device components are suitable.	40	35	88 %	[95; 74]
Are the specified device components clearly defined, meaning their description is understandable?	40	34	85 %	[93; 71]
Are the specified device components clearly defined, meaning their description is complete?	40	31	78 %	[88; 62]

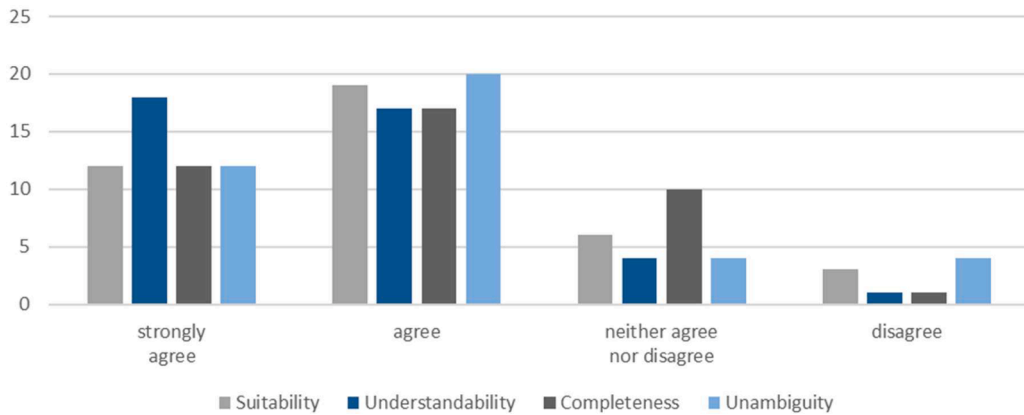


Fig. 5. Survey results – software component specification.

Table 11
Survey results – software component specification.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
The defined software components are suitable.	12 (30 %)	19 (47.5 %)	6 (15 %)	3 (7.5 %)		2
Are the specified software components clearly defined, meaning their description is understandable?	18 (45 %)	17 (42.5 %)	4 (10 %)	1 (2.5 %)		2
Are the specified software components clearly defined, meaning their description is complete?	12 (30 %)	17 (42.5 %)	10 (25 %)	1 (2.5 %)		2
Are the specified software components clearly defined, meaning their description is unambiguous?	12 (30 %)	20 (50 %)	4 (10 %)	4 (10 %)		2

Table 12
Software component specification – confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
The defined software components are suitable.	40	31	78 %	[88; 62]
Are the specified software components clearly defined, meaning their description is understandable?	40	35	88 %	[95; 74]
Are the specified software components clearly defined, meaning their description is complete?	40	29	73 %	[84; 57]
Are the specified software components clearly defined, meaning their description is unambiguous?	40	32	80 %	[90; 65]

median of “agree”. One expert recommended that the use cases could be expanded to offer more detailed insight. Another participant noted that the case studies do not consider all stakeholders, which were previously specified. The understandability, completeness, and unambiguity, of the use cases, were evaluated positively with a median of “agree”. However, completeness and unambiguity were rated worse than understandability, underlining the expert’s comment.

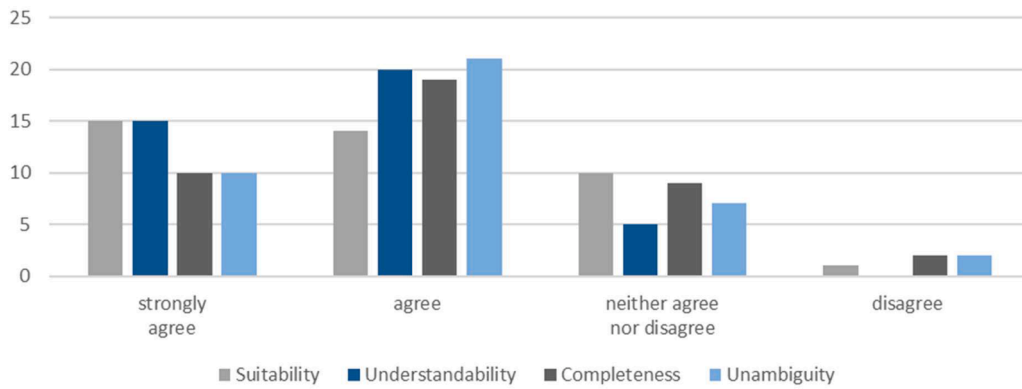


Fig. 6. Survey results – use case description.

Table 13

Survey results – use case description.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
Are the use cases clearly defined, meaning their description is complete?	15 (37.5 %)	14 (35 %)	10 (25 %)	1 (2.5 %)		2
Are the use cases clearly defined, meaning their description is unambiguous?	15 (37.5 %)	20 (50 %)	5 (12.5 %)			2
Based on the initial requirements, the presented use cases are suitable.	10 (25 %)	19 (47.5 %)	9 (22.5 %)	2 (5 %)		2
Are the use cases clearly defined, meaning their description is understandable?	10 (25 %)	21 (52.5 %)	7 (17.5 %)	2 (5 %)		2

Table 14

Understandability of use case description – confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
Are the use cases clearly defined, meaning their description is complete?	40	29	73 %	[84; 57]
Are the use cases clearly defined, meaning their description is unambiguous?	40	35	88 %	[95; 74]
Based on the initial requirements, the presented use cases are suitable.	40	29	73 %	[84; 57]
Are the use cases clearly defined, meaning their description is understandable?	40	31	78 %	[88; 62]

Summary of the survey results of the specification chapters

The mean of all 40 replies concerning fittingness, respectively suitability, understandability, completeness and unambiguity is “agree”. The numbers of positive responses, including “strongly agree” and “agree” range from 25 to 36. For better visualization, the results are summarized in the below diagram. The bars represent the number of positive replies, and the candle sticks display the confidence intervals with their upper and lower end representing the upper and lower levels.

Evaluation of IoT specification feasibility and suitability

The majority of experts strongly agreed or agreed that the generated IoT specification is feasible. The recommended changes concentrate on recommendations for the specifications content and technical improvements of the IoT system.

To improve the feasibility of the specification, experts recommended including more technical information, like specifying the response times more precisely. Furthermore, it was noted that the problem statement needs to be clearer, and the proposed solution needs to be more specific. Moreover, the handling of sensor data (fusion, reduction, transmission, speed) and technical incompatibilities between different system components as well as the number of devices managed by the system need to be described in more detail. One participant recommended adding context-based nodes for specifying the security system with ChatGPT.

To improve the feasibility of the system, experts recommended decreasing the complexity of the system, to reduce costs, and ease of connectivity in the network. It was recommended to compress the transmitted data to reduce energy consumption and to improve the confidentiality of the system. Furthermore, it was noted to improve the ability of users to intervene with the system’s automatic controls. The implementation of AI technologies like machine learning was also recommended [16].

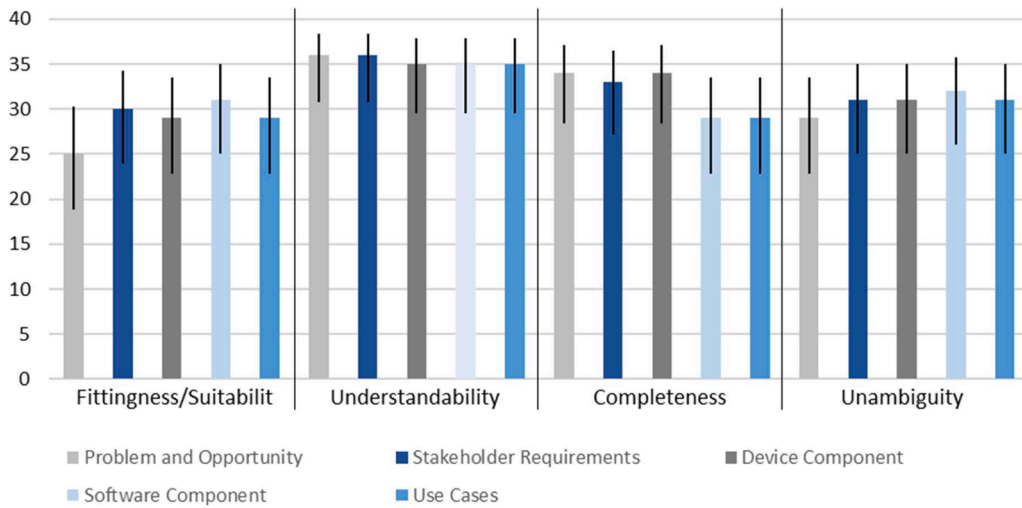


Fig. 7. Summary of positive answers.

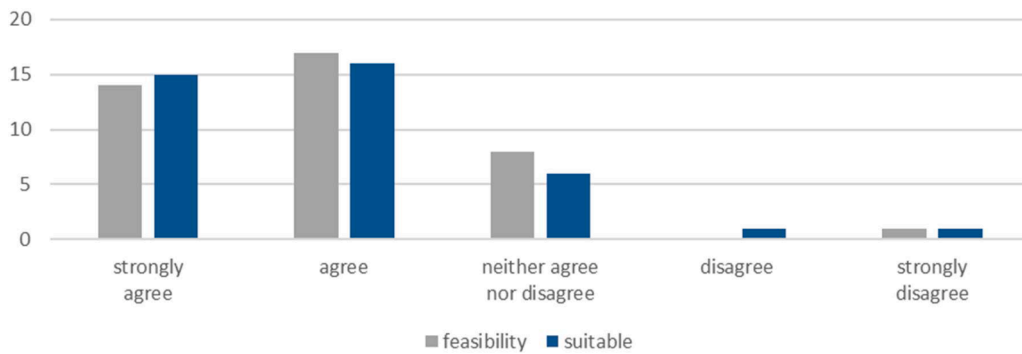


Fig. 8. Survey results – feasibility and suitability of IoT specification.

Table 15

Survey results – feasibility and suitability of IoT specification.

Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Median
How feasible is the described IoT specification?	14 (35 %)	17 (42.5 %)	8 (20 %)	1 (2.5 %)		2
Would you deem the created IoT specification as suitable for the intended use case?	15 (38.5 %)	16 (41 %)	6 (15.4 %)	1 (2.6 %)	1 (2.6 %)	2

Table 16

Feasibility and suitability of IoT specification – confidence intervals.

Statement	Number of total responses	Number of positive responses	Proportion of supportive responses	[UL; LL]
How feasible is the described IoT specification?	40	31	78 %	[0.88; 0.62]
Would you deem the created IoT specification as suitable for the intended use case?	39	31	79 %	[0.89; 0.64]

Similar to the feasibility, most experts agreed or strongly agreed that the created IoT specification is suitable for the intended use case. The experts recommended further details on the daily usage of the system and its operation modes and to improve the presentation of the reference architecture. One expert noted that the specification should provide more details on how the collected data is

used to control the existing subsystems. Furthermore, it was recommended to perform a comparative analysis with the existing solution and to test different Google services that could easily provide specified capabilities.

Comparison of the generated specification with the implemented system

In this chapter, the specification created with ChatGTP is compared to the real, implemented system, described in the paper [18], to determine their differences and similarities. To begin with, a summary of the implemented IoT system is presented, listing its key features. Afterwards, the individual chapters of the specification are analyzed and compared to the implemented system based on the information presented in the paper. In the end, a conclusion is drawn.

The implemented IoT system

Custom IoT boards were used to integrate sensors and electric devices into the IoT network. These boards consist of an Arduino UNO and an ESP 8266 Wi-Fi module, current transformers, and relays. Each of these boards can connect to three other devices, including other boards, a Raspberry Pi acting as a communication broker, and the users, together forming a wireless IoT network [18].

For communication in the network, the Message Queuing Telemetry Transport protocol was used. The electrical appliances and sensors act as MQTT clients, the Raspberry Pi3, running Node-Red and Mosquitto, acts as an MQTT broker. The electrical appliances connected to the network are controlled via MQTT messages sent by a mobile phone via an app specifically developed for that purpose in Android Studio [18].

The status (ON/OFF) of each appliance is monitored by measuring the current. The status is published to the broker and displayed on a dashboard in Node-Red. In total, information about temperature, humidity, and light intensity in the laboratory is monitored and visualized on the dashboard. The status history of the device is saved on a designated database. For further transmission and processing, the IoT analytics platform ThingSpeak was used, which allows instant visualization of the data posted by the devices [18].

Comparison of the specification and the implemented system

Project problem and opportunity. Out of the five identified problems/opportunities three were realized by the laboratory IoT system, namely the reduction of energy consumption, monitoring and control of subsystems, and the lack of status visibility of the subsystems in the laboratory. Management of physical resources such as classrooms, laboratories meeting rooms, and equipment, and the coordination of laboratory activities for more efficient space utilization in the laboratory were not part of the realized solution.

Stakeholder requirements. Out of the 24 specified functional requirements, seven can be considered as fully implemented, three were partly implemented, and 14 were not implemented. The quality characteristics described in the specification, cannot be assessed as the needed information is not present in the paper.

The comparison of stakeholder requirements to the real, implemented system shows, that many of the specified requirements are not in the scope of the system. A significant improvement to avoid such wrong stakeholder requirements would be the implementation

Table 17

Comparison of stakeholder requirements.

Functional requirements	Status	Comment
1a. Resource Allocation	not imp.	Not in the scope of the implemented system.
1b. Real-time Resource Monitoring	not imp.	Not in the scope of the implemented system.
1c. Reports and Analytics	not imp.	Not in the scope of the implemented system.
2a. Energy Consumption Insights	imp.	Visualized on a dashboard
2b. Energy Wastage Detection	part. imp.	The presence/absence of people in the lab is not detected.
2c. Demand-Response Capability	imp.	The brightness of light is adjusted based on daylight.
3a Real-time Infrastructure Monitoring	part. imp.	Only connected devices in the laboratory are monitored.
3b Predictive Maintenance	not imp.	Not in the scope of the implemented system.
3c Asset Tracking	not imp.	Not in the scope of the implemented system.
4a. Secure IoT Infrastructure	not imp.	Not in the scope of the implemented system.
4b. Scalability and Flexibility	imp.	Network design and communication are scalable
4c. Monitoring and Troubleshooting Tools	part. imp.	No information is present about troubleshooting tools.
5a. User-friendly Interface	imp.	Node-RED dashboard providing information.
5b. Smart Space Utilization	not imp.	Not in the scope of the implemented system.
5c. Enhanced Learning Environment	imp.	The system illustrates different technologies used in IoT systems
6a. Energy Efficiency Metrics	imp.	Energy consumption is monitored, and historical data is stored.
6b. Sustainability Insights	imp.	Energy data is analyzed for further insights.
7a. Smart Access Control	not imp.	Not in the scope of the implemented system.
7b. Real-time Surveillance	not imp.	Not in the scope of the implemented system.
8a. Cost-saving Measures	not imp.	Not in the scope of the implemented system.
8b. Financial Reporting	not imp.	Not in the scope of the implemented system.
9a. Compatibility and Integration	not imp.	Not in the scope of the implemented system.
9b. Long-term Support	not imp.	Not in the scope of the implemented system.
10a. Compliance and Reporting	not imp.	Not in the scope of the implemented system.

of intermediate steps to validate them by the stakeholders. However, the generated specification does cover all aspects of the implemented system.

Device component specification. Out of the 16 specified device components 2 are fully implemented, 5 are partially implemented, 3 are not implemented and the remaining 6 cannot be assessed, as there is no information given regarding their realization in the implemented system.

The evaluation and comparison of the device components with the implemented system shows, that ChatGPT outlines many components correctly, and deviations result from differences based on the stakeholder requirements. However, the description of the individual device components partially contains meaningless requirements. For example, the environmental sensors should be powered by battery or power over Ethernet, excluding the option to power it via the electrical network, while the smart meters should only be powered by the electrical network. Similarly, to the results of the comparison of the stakeholder requirements, ChatGPT shows that it can specify device components, however, it also lists many that are not implemented.

Software component specification. For the analysis of the software components, only the components for which the corresponding device components are implemented or partially implemented were analyzed. For improved readability, the functional and non-functional requirements are evaluated in separate tables. The interface requirements of all software components are fully implemented and therefore are not individually listed. Out of 7 functional requirements, 2 are fully implemented, and the remaining 5 are considered partially implemented. 4 of the 7 nonfunctional requirements are partially implemented, for the remaining 3 cannot be assessed as there is no information in the paper.

Most of the functional requirements of the software components, of which the device components are implemented, are realized. This demonstrates that the generated functional requirements of the software components are fitting for the intended use. Concerning the interface requirements, it is noteworthy, that there is little variety within them for different components. Furthermore, some specified software requirements contain the same content and description as in the device component specification.

Evaluation of the use cases. Out of the three described use cases, only one can be considered as a correct reflection of the applications of the real system, namely use case 2, which focuses on energy optimization and monitoring of energy consumption.

Table 18
Comparison of device components.

Device component	Status	Comment
1. Occupancy Sensors	not imp.	Not in the project scope
2. Environmental Sensors	part. imp.	CO2 sensors are not implemented; powered by the electrical network instead of batteries
3. Smart Meters	imp.	Implemented as specified
4. Smart Locks and Access Control Systems	not imp.	Not in the project scope
5. Web-Based Interface	part. imp.	Features cannot be assessed
6. Mobile App	part. imp.	App only for Android devices; encryption and user authentication cannot be assessed
7. Cloud-Based Data Platform	part. imp.	Uncertain if data storage is in the cloud
8. Data Analytics and Algorithms	no inf.	
9. IoT Gateway	part. imp.	Firewall and encryption cannot be assessed.
10. Demand-Response Mechanism	not imp.	
11. Subsystem Monitoring and Maintenance System	no inf.	
12. Notifications and Alerts	no inf.	
13. Security and Access Control Infrastructure	no inf.	
14. Integration Interfaces	not imp.	
15. User Interface Design and User Experience	imp.	Implemented as specified
16. Training and Support Services	no inf.	

Table 19
Comparison of functional requirements of software components.

Functional requirements		
Software component	Status	Comment
2. Environmental Sensors	part. imp.	The mechanism for calibration and accuracy checks cannot be assessed.
3. Smart Meters	imp.	
5. Web-Based Interface	part. imp.	Classroom scheduling is not in scope. User authentication and access control cannot be assessed.
6. Mobile App	part. imp.	Notifications and alerts as well as diagnostic tools cannot be assessed
7. Cloud-Based Data Platform	imp.	
9. IoT Gateway	part. imp.	Secure data transmission cannot be assessed.
15. User Interface Design and User Experience	part. imp.	It cannot be assessed if accessibility features for disabled users are implemented.

Table 20

Comparison of nonfunctional requirements of software components.

Nonfunctional requirements		
Software component	Status	Comment
2. Environmental Sensors	part. imp.	Responsiveness and encryption of data transmission cannot be assessed.
3. Smart Meters	part. imp.	High accuracy and precision as well as secure communication cannot be assessed.
5. Web-Based Interface	part. imp.	Secure communication cannot be assessed.
6. Mobile App	part. imp.	No cross-platform compatibility; Security and data encryption cannot be assessed.
7. Cloud-Based Data Platform	no inf.	
9. IoT Gateway	no inf.	
15. User Interface Design and User Experience	no inf.	

Table 21

Comparison of use case description.

Use case	Status	Comment
1. Classroom Resource Allocation	not imp.	Not in the scope of the implemented system
2. Smart Energy Demand-Responds	part. imp.	The implemented system regulates the light level in the laboratory based on daylight intensity, to reduce the energy consumption of the lights during daytime. However, there are no mentions in the paper describing any effect of extreme weather conditions on the system, respectively the system having specific settings to adjust to such.
3. Subsystem Monitoring and Proactive Maintenance	no inf.	There is no information presented in the description of the implemented system, that details any condition monitoring of subsystems, maintenance alerts, and inspection and maintenance planning.

Discussion

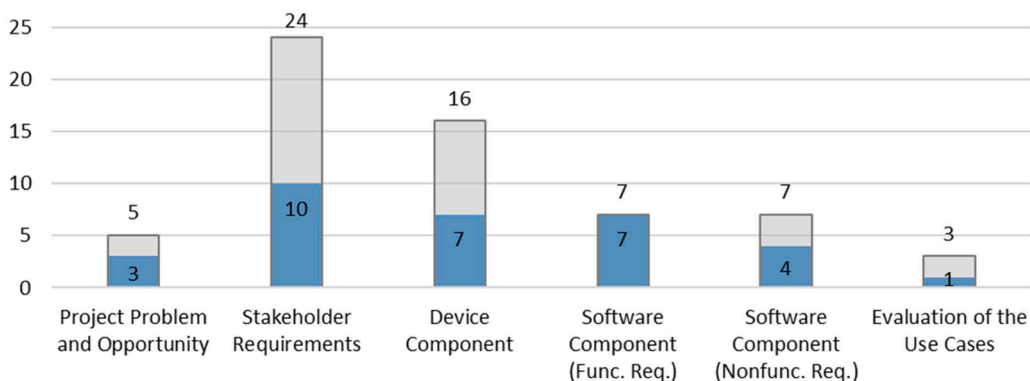
In total, out of the 24 stakeholder requirements, 14 were not in the scope of the real system, 3 were implemented partially and 7 were fully realized. The comparison of the device component specification shows that out of the 16 specified components only 10 could be assessed due to the deviations resulting from the stakeholder requirements. Out of the ones that could be assessed, 2 were fully and 5 were partially implemented, resulting in about half of the specified device components being recognized. For the software components, only 7 corresponding device components were at least partially implemented. 2 functional requirements were fully and 5 were partially implemented. 4 nonfunctional requirements were partially implemented, the remaining 3 were not assessed.

Fig. 9 below summarizes the results. The grey bars represent the total number of evaluated items in each category and the blue bars illustrate the number of implemented and partially implemented items.

Fig. 9 indicates that early realignment of the generated content is necessary, to improve the fit of the content created in later tasks, ensuring that the IoT specification adheres to the intended scope. The issue of not realigning the specification early in the proposed model becomes even more prominent when comparing the specified use cases to the real system. Out of the 3 generated use cases, only one was assessed properly, due to the other use cases not being in the scope of the implemented system.

Thus, ChatGPT proved to be a promising tool for content generation for IoT specifications and for creating creative proposals for IoT solutions, but without aligning the process to the customers' needs, the resulting specification yields requirements and system features that are not in the scope of the intended IoT solution. Therefore, validation and adaptation through the stakeholders are needed.

Based on the result of the empirical study, the framework, presented in Fig. 1, was updated. The new process model includes tasks for validation and adaption of the generated content of ChatGPT, to ensure a better fit of the specified content to the stakeholder needs. The improved framework is illustrated in Fig. 10.

**Fig. 9.** Summary of comparison.

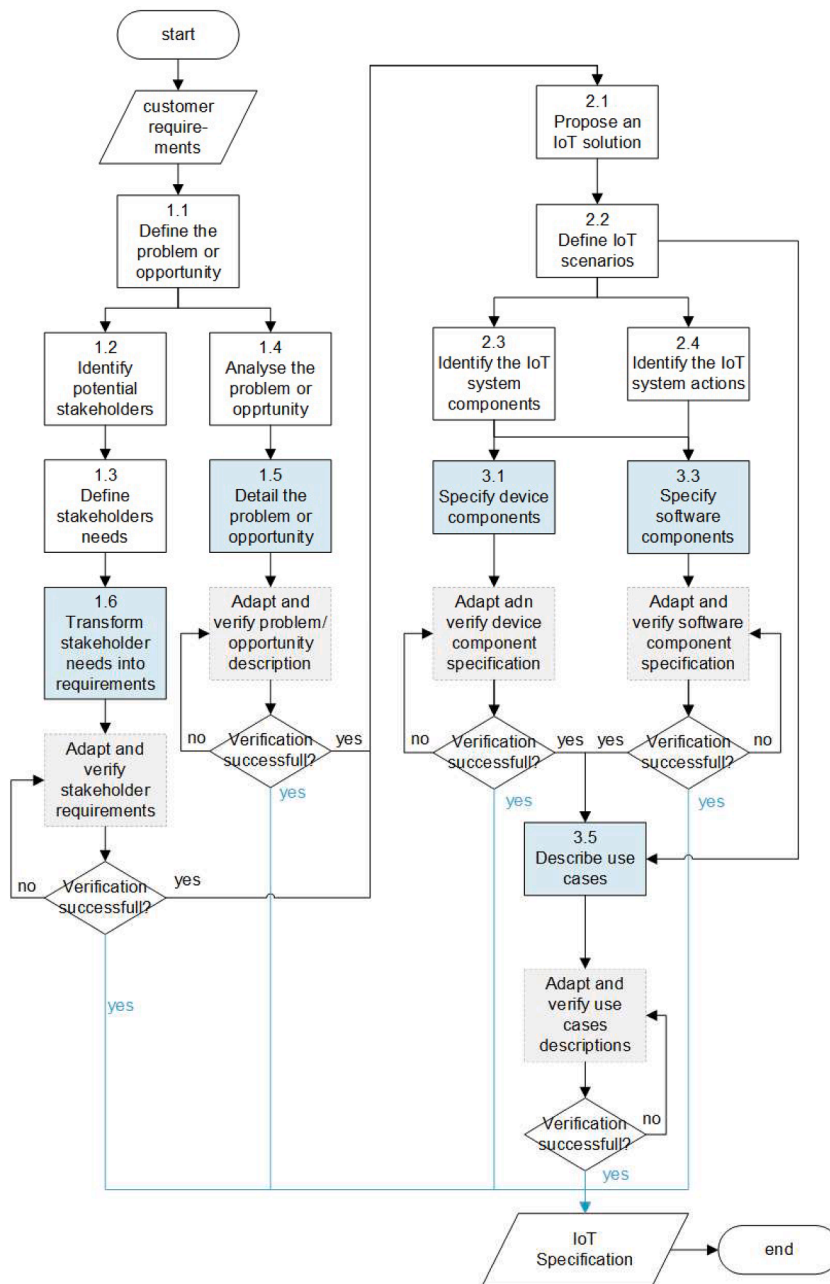


Fig. 10. Improved framework for the generation of the IoT systems specification with ChatGPT.

The improved process model includes five additional tasks and decisions that encompass the adaptation and validation of the content, generated by ChatGPT through the stakeholders. They are arranged to allow for realignment and adaption of the content after each task, ensuring that only validated content is used as further input in the process and presented within the specification.

The results of the survey show, that most experts agreed that the IoT specification, generated with ChatGPT, is complete, understandable, unambiguous, feasible, and suitable. These are promising results for the application of ChatGPT for the creation of IoT specifications. However, in this research, only a single use case was tested and evaluated. Additional use cases need to be used for systems of different complexity and scope to prove the applicability of ChatGPT for IoT system specifications.

Limitations of using ChatGPT for the generation of IoT specification

The limitations of using ChatGPT for the generation of IoT specifications and framework design were identified through a combination of survey responses from experts and the practical testing of the process model developed in the study. The authors identified

ChatGPT's limitations based on several key aspects:

1. **Token Size Limitation:** The maximum token size of ChatGPT, specifically GPT-3.5 Turbo used in this research, is 4096. This limitation means that when dealing with large, complex IoT systems requiring lengthy prompts and responses, there's a risk of reaching the token limit. This could necessitate splitting the text into multiple parts for separate processing, which was not tested in this study and could lead to undesirable outcomes.
2. **Handling Complex Systems:** Working with complex IoT systems using the ChatGPT web interface becomes cumbersome due to the need for precise attention to copying and feeding back exact prompts and responses. This issue could be mitigated by using ChatGPT's API with a script, improving the stability and performance of the process model.
3. **General Nature of ChatGPT:** ChatGPT is a general language model not specifically trained for IoT systems. It uses training data from various internet sources, which may not sufficiently cover domain-specific information required for more complex IoT systems [21]. This could lead to inaccuracies or gaps in the generated specifications.
4. **Survey Feedback:** The survey conducted among experts highlighted that while ChatGPT could generate understandable, complete, and unambiguous IoT specifications, there were notable differences when comparing these specifications to a real implemented system. Specifically, certain features defined in the specifications were out of scope for the real system, indicating a need for a process to verify and align generated content with actual system requirements and stakeholder needs.

The limitations were systematically identified through the direct application of the ChatGPT model in creating IoT specifications, testing the model's output against actual system implementations, and gathering expert feedback on the suitability and accuracy of the generated content. This comprehensive approach allowed the authors to pinpoint specific areas where ChatGPT's application in IoT system specification and framework design falls short, suggesting areas for improvement and further research.

Also, integration of LLM into existing IoT development workflows poses a significant challenge, particularly in environments controlled by regulatory requirements of companies. Achieving effective integration may require the implementation of additional tools and processes. Given considerations emphasize the importance of ongoing research and development aimed at addressing the specified above challenges. By doing so, researchers can enhance the effectiveness and applicability of AI language models in specialized domains such as IoT system specification and framework design.

Conclusion

The paper develops a framework to test the applicability of ChatGPT to create IoT specifications, based on initial customer requirements. These initial requirements are provided in unstructured written text containing a rough explanation of the needs, desires, and problems that should be addressed, and the opportunity the system should realize. A framework was developed based on the work of [20], who created a requirement engineering process model tailored for IoT systems based on the ISO IEC/IEEE 12,207:2017. The derived subprocesses were combined and adapted to develop a new process model, comprising a chain of tasks that ChatGPT could reliably perform to generate the individual items of content that are combined into the final specification.

The proposed framework was demonstrated with a use case encompassing the implementation of an IoT system for a campus laboratory, described by [18]. The resulting specification was compared to the description of the implemented system and validated in the experts' survey to assess the specifications' quality and content. The quality was determined by evaluating the specifications' understandability, completeness, and unambiguity. The content was evaluated based on its suitability in comparison to the initial requirements and the feasibility of the specification.

In total, 40 experts participated in the survey. Most of them agreed that the generated draft of the specification is understandable, complete, and unambiguous. Likewise, to the quality of the specification, most experts consented that the specification is feasible and suitable. These results show that ChatGPT is capable of generating IoT specifications of good quality and content, although several experts noted that they were missing technical details.

The comparison of the generated specification and the description of the implemented system shows the correspondence of the implemented devices and software components to the ones, described in the generated specification. However, several features in the generated specification were out of the scope of the real system.

In conclusion, ChatGPT showed promising results for generating a draft of IoT specifications with a feasible solution in the tested use case scenario. Due to the lack in the initial framework of the means to ensure that the generated specification aligns with the needs of the stakeholders, an improved model was developed that emphasizes collaboration between experts, stakeholders, and ChatGPT to yield better fitting results. The improved process model does not solely rely on ChatGPT but treats it as a tool for experts and stakeholders that potentially reduces the time and effort needed to create IoT system specifications, as it supports them with the creation of quality content.

While ChatGPT is not specifically designed for IoT systems, but rather a generally trained language model, the research proved that end-users, utilizing the proposed process model, could reduce the time and effort needed to create IoT system specifications.

CRedit authorship contribution statement

Mario Binder: Writing – original draft, Validation, Investigation. **Vitaliy Mezhuzev:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

Initial Requirements - Input

“As the campus grows every year, new management problems and energy issues appear. Managing the resources in the campus has become a real problem. Monitoring and controlling the unused devices that consume power during human absence is also a major inability. In addition to this, coordinating the people participating in the daily activities of the laboratory is tedious when the population of the usage of the space outnumbers a manageable threshold. Another problem is power management. It is difficult to monitor all subsystems such as lighting, projecting and air conditioning systems. But if these are left indiscriminately, energy will be wasted. People cannot check the status of the sub-system at ease.”

Project Problem and Opportunity – a Sample of the Output

The problem/opportunity to be addressed is the lack of efficient and effective resource management within the campus due to its continuous growth and increasing complexities. The campus faces several challenges related to resource allocation, energy consumption, space utilization, and subsystem monitoring, which have a significant impact on the campus's overall functionality, sustainability, and cost-effectiveness.

1. Resource Management Challenge:

As the campus grows, new management problems and energy-related issues emerge, making it increasingly difficult to handle resources efficiently. This includes managing physical resources such as classrooms, laboratories, meeting rooms, and equipment, as well as human resources such as faculty and staff allocation.

2. Energy Consumption and Wastage:

One of the major issues is the consumption of power by devices during periods of human absence, leading to unnecessary energy wastage. The lack of control over such devices contributes to increased energy costs and negatively impacts the campus's environmental footprint.

3. Space Utilization Inefficiencies:

Coordinating daily activities within the laboratory becomes cumbersome when the number of users exceeds a manageable threshold. Inefficient space utilization leads to wasted space, overlaps, and difficulties in booking appropriate facilities for specific activities.

4. Subsystem Monitoring and Control:

The campus has various subsystems, including lighting, projecting, and air conditioning systems, which are challenging to monitor and control effectively. This lack of monitoring can lead to energy inefficiencies and increased operational costs.

5. Lack of Status Visibility:

The absence of an easily accessible system to check the status of subsystems hinders proactive decision-making. This lack of visibility results in potential energy wastage and management inefficiencies.

The opportunity lies in implementing an IoT-based system that offers smart and automated solutions for resource management, energy efficiency, space utilization, and subsystem monitoring. Such a system would integrate various IoT devices, sensors, data communication networks, and data analytics tools to achieve real-time monitoring, control, and optimization of campus resources.

The IoT system aims to address the following aspects:

1. **Efficient Resource Allocation:** The system should enable campus administrators to allocate resources effectively, optimize facility usage, and enhance resource utilization.
2. **Energy Efficiency and Savings:** By monitoring and controlling energy-consuming devices, the IoT system can reduce energy wastage during periods of human absence and improve campus sustainability.
3. **Smart Space Utilization:** Through real-time monitoring and data analysis, the system can provide insights into space utilization patterns and optimize room booking processes.
4. **Subsystem Monitoring and Optimization:** The IoT system will enable real-time monitoring of various subsystems, allowing for proactive maintenance and energy optimization.
5. **Enhanced Visibility and Control:** Users, administrators, and management will have easy access to the status of subsystems and overall campus resources, enabling data-driven decision-making and improving campus management.

Stakeholder Requirements – a Sample of the Output

1. Campus administration requirements:

	Function	Quality characteristic
a. Resource Allocation	The IoT system should provide resource allocation algorithms based on demand and historical usage data.	Accuracy in predicting resource demand and efficient allocation
b. Real-time Resource Monitoring	The IoT system should continuously monitor resource usage and provide real-time status updates.	Real-time data refresh rate, low latency, and reliable alerts for anomalies.
c. Reports and Analytics	The IoT system should generate detailed reports and analytics on resource usage and efficiency.	Comprehensive and customizable reports, data visualization, and ease of data interpretation.

2. Energy management team requirements:

	Function	Quality characteristic
a. Energy Consumption Insights	The IoT system should collect and analyse energy consumption data from various devices and subsystems.	The granularity of energy data, accurate analytics, and actionable insights for optimization.
b. Energy Wastage Detection	The IoT system should identify instances of energy wastage caused by devices operating during human absence.	Real-time detection accuracy, and reduction of wasteful energy consumption.
c. Demand-Response Capability	The IoT system should optimize energy usage during peak hours based on demand-response strategies.	Real-time responsiveness, adaptive energy management algorithms.

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