

# A Requirements Engineering Technology for the IoT Software Systems

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**Abstract** Contemporary software systems (CSS) – such as the internet of things (IoT) based software systems – incorporate new concerns and characteristics inherent to the network, software, hardware, context awareness, interoperability, and others, compared to conventional software systems. In this sense, requirements engineering (RE) plays a fundamental role in ensuring these software systems' correct development looking for the business and end-user needs. Several software technologies supporting RE are available in the literature. However, many do not cover all CSS specificities, notably those based on IoT. This paper presents RET<sub>IoT</sub> (Requirements Engineering Technology for the Internet of Things-based software systems). It aims to provide methodological, technical, and tooling support to produce IoT software system requirements document. In addition, it comprises an IoT scenario description technique, a checklist to verify IoT scenarios, construction processes, and templates for IoT software systems. A feasibility study was carried out in IoT system projects to observe its templates and identify improvement opportunities. The results indicate the feasibility of RET<sub>IoT</sub> templates' when used to capture IoT characteristics. However, further experimental studies represent research opportunities, strengthen confidence in its elements (construction process, techniques, and templates), and capture end-user perception.

**Keywords:** *Software Engineering, Requirements Engineering, Internet of Things, IoT Software Systems, Software Systems Specification, Software system requirements document, Software technology*

## 1 Introduction

Contemporary software systems, such as those inherent to the Internet of Things (IoT) paradigm, are complex compared to conventional software systems. This complexity comes from the inclusion of new concerns and characteristics related to network, software, hardware, context awareness, interface, interoperability, and others (Motta et al., 2019a) (Nguyen-Duc et al., 2019).

IoT-based software systems seek to promote the interlacement of technologies and devices that, through a network, can capture and exchange data, make decisions, and act. With these actions, they unite the real and virtual worlds through objects and tags. However, building IoT software systems is not a trivial activity due to its specific technological characteristics. It requires adapted and/or innovative software technologies to create and guarantee the quality of the built product (Motta et al., 2019a).

The quality of contemporary software systems' development depends on software technologies that respond to these systems' new concerns and characteristics. As with any other product built on engineering principles, a key activity in developing IoT software systems is constructing the requirements document. Defects present in the requirements document can cause an increased time, cost, and effort for the project; dissatisfied customers and end-users; low reliability of the software system; a high number of failures; among others (Vegendla et al. 2018) (Arif et al. 2009).

Requirements engineering (RE) is responsible for the life cycle of the requirements document. It ensures its proper construction (Vegendla et al. 2018) (Pandey et al., 2010). The RE phases and activities may differ according to the application domain, people involved, processes, and organizational culture. However, we can observe some recurring phases and RE activities, such as conception/design, elicitation, negotiation, analysis, specification, verification, validation, and management.

The technical literature presents several software technologies to support RE for software systems. However, not all of them cover the different RE phases and, mainly, IoT software systems' specificities. In this work, the term "software technology" refers to the methodological, technical, and tooling offered by the works to support the construction of requirements document for IoT software systems.

Considering the need for appropriate software technologies to develop IoT software systems and understand the importance of requirements document for the stability, adequacy, and quality of a project, this work proposes the RET<sub>IoT</sub> (Requirements Engineering Technology for the Internet of Things software systems).

The RET<sub>IoT</sub> consists of a requirements specification technique based on IoT scenarios description - SCENARI<sub>IoT</sub> (Silva 2019), an IoT scenario inspection technique - SCENARI<sub>IoT</sub>CHECK (Souza 2020), a construction process, and templates to support the processes activities and build the requirements document.

The SCENARI<sub>IoT</sub> and SCENARI<sub>IoT</sub>CHECK techniques were previously evaluated through experimental studies, which indicated their feasibility (Souza et al. 2019a) and usefulness (Souza et al. 2019b). Moreover, they have been used in IoT software system projects developed by the Experimental Software Engineering (ESE) Group in the context of DELFOS – The Observatory of Engineering Contemporary Software Systems – COPPE/UFRJ.

Based on the experiences with these projects, the construction process and templates of RET<sub>IoT</sub> evolved. This article extends a previous publication of RET<sub>IoT</sub> (Silva et al. 2020b). The first version (Silva et al. 2019) encompasses many RE activities. It focuses on the definition of Project scope, IoT system, and IoT system requirements. The second version (Silva et al. 2020b) focuses on eight RE phases: Conception, IoT elicitation, IoT analysis, IoT specification, IoT verification, Negotiation, Validation, and Management. The templates of this version are evaluated through a feasibility study

(section 4). The third version (Silva et al. 2020a) involves the different RE phases through an engineering cycle divided into eight phases: IoT ideation and conception, IoT elicitation, IoT analysis, IoT specification, IoT verification, Negotiation, IoT evaluation, and Management. Their templates are evaluated through a proof of concept. The fourth and current version of the technology includes improvements in the construction process and templates. Optional activities and tasks were analyzed and incorporated into the construction process. The focus and perspective of the process were changed to IoT product and project, including product ideation and evaluation concepts. Also, the engineering cycle was compacted to simplify the construction process that includes four phases instead of eight of the third version. The templates were evolved in the current version to include the gaps and improvements identified during the proof of concept (Silva et al. 2020a).

For the sake of completeness and applicability, this paper presents the current (fourth) version of  $RET_{IoT}$ , including a feasibility study comparing three  $RET_{IoT}$  templates with regular ones used to build requirements document for conventional software systems. The results indicate that  $RET_{IoT}$  templates allow capturing the information needed for IoT software systems and that they are mature to be evaluated in constructing such requirements document. Furthermore, it is also possible to observe that the technology covers the main RE phases and activities concerning IoT-based projects.

Beyond this introduction, this article presents six other sections. Section 2 describes the technological basis of the  $RET_{IoT}$ . Next, Section 3 introduces and details the  $RET_{IoT}$ . Section 4 demonstrates the feasibility study. Section 5 presents some related works found in the literature. Section 6 discusses some research opportunities. Finally, section 7 presents future work and concludes the article.

## 2 The Technological Basis of the $RET_{IoT}$

This section presents the technological basis used to build the  $RET_{IoT}$  to support RE in IoT software systems. Such a requirements technology is inserted in the context of a systems engineering approach, which concerns the major development stages of IoT software systems (Motta et al. 2020). Its technological basis is composed of two empirically evaluated techniques, the  $SCENARI_{IoT}$  and  $SCENARI_{IoT}CHECK$  techniques.

### 2.1 $SCENARI_{IoT}$

Conventional software scenarios can be used in any software system and development stage. They can cover different purposes, such as eliciting requirements, specifying requirements, validating requirements, and testing (Glinz 2000) (Behrens 2002) (Alexander and Maiden 2004). A scenario is a sequence of events describing the system behavior and its environment (Burg and Van de Riet 1996) or an ordered set of interactions between partners - usually systems and external actors (Glinz 2000). It represents requirements through stories describing the system from the users' perspective

when applied to requirements engineering (Glinz 2000) (Alexander and Maiden 2004).

Scenarios offer many advantages: they are based on the users' point of view; ii) the possibility to carry out partial specifications; iii) easy to understand; iv) enable short feedback loops; and v) provide a basis for testing the system (Glinz 2000). Thus, scenarios constitute a good basis for communication with clients and laypeople (non-technical) because they can be easily understood and do not require prior understanding. Therefore, everyone involved at different levels and functions can express opinions and identify problems (Glinz 2000) (Behrens 2002) (Alexander and Maiden 2004).

The  $SCENARI_{IoT}$  (Silva 2019) is a specification technique that adapts conventional scenarios to support IoT software systems' specifications. It considers the characteristics (adaptability, connectivity, privacy, intelligence, interoperability, mobility, among others) and behaviors (identification, sensing, and actuation) specific to these software systems (Motta et al., 2019b). The combination of characteristics and behaviors led to the creation of nine IoT Interaction Arrangements (IIAs).

IoT interaction arrangements represent frequent interaction flows between things and other non-IoT elements, such as conventional software systems and end-users. Each IIA has a catalog containing all relevant information captured and used in the scenario's description. The cardinality for arrangements and scenarios is a many-to-many relationship (M:N). Therefore, many arrangements (isolated or combined) relate to one or more IoT scenarios. An IoT scenario can be linked to one or more arrangements.

The IIAs, together with their catalogs, guide software engineers to capture essential information about the system: i) identification of the "things" and system components; ii) the types of data that will be collected and displayed; iii) the actions that will be performed in the environment; iv) aspects related to decision making on a particular system context; v) the actors (end-users, software systems, things, among others) who will access the data; among others. **Figure 1** shows the "IIA-1: Display of IoT data" arrangement and its catalog.

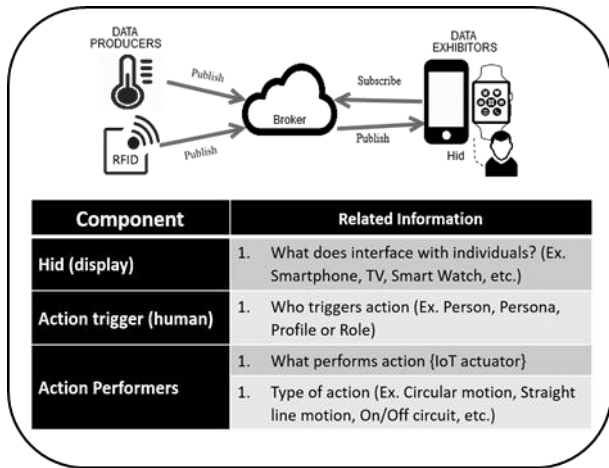


Figure 1. "IIA-1: Display of IoT data" arrangement (Silva 2019).

## 2.2 SCENARI<sub>OT</sub>CHECK

The SCENARI<sub>OT</sub>CHECK is a checklist-based software inspection technique specialized in verifying IoT software system scenarios (Souza 2020). This technique aims to assist inspectors in detecting defects in IoT scenario descriptions, guaranteeing their quality. It was created to work together with the SCENARI<sub>OT</sub> technique since it produces the input to SCENARI<sub>OT</sub>CHECK.

The SCENARI<sub>OT</sub>CHECK checklist consists of two parts. The first part (general questions) aims to identify defects related to project information and systemic solution such as i) problem domain; ii) interaction and identification among actors, system, hardware, and devices; iii) alternative and exception flow; among others. **Table 1** shows the first part of the questionnaire.

Table 1. Questions on the SCENARI<sub>OT</sub> Specification Technique.

Nº	Question
01	Has the overall application domain been established? (Health, leisure, traffic)
02	Is the specific purpose of the system correctly described? (Data visualization, decision making, and/or actuation only)
03	Is the type of data collected specified? (Temperature, humidity, pollution, and so on)
04	Is it possible to identify who or what collects the data? (Sensors, QR code readers, and so on)
05	Is it possible to identify who or what manages the data collected? (Administrator, decision-maker, users, and so on)
06	Is it possible to identify who or what accesses the data collected? (Things, software systems or users)
07	Is the user interface device that displays the data described? (dashboard, smartphone, tablet, and so on)
08	Is it possible to identify who is viewing the data? (Things, software systems, users, and so on)
09	Is it possible to identify the source from which the data is provided? (Chairs, table, automobiles, houses, buildings, and so on)
10	Are the roles involved in the system described? (Things, software systems, users, and so on)
11	Is there any description of each actor in the specified scenarios?
12	Is it possible to identify the source of data provision?

- 13 Has each action within the scenario been described clearly and contains no extraneous information?
- 14 Is there a sequence of ambiguous actions in the scenarios? Are the actors described in the scenarios consistent with the actors described in the arrangements? (Things, software systems, users)
- 15 Are the scenarios related to the arrangements consistently? Do the scenarios seek to be accurate by presenting title and flows? (Presenting the purpose and actions of the system directly and explicitly)
- 16 Are adverbs avoided in order not to generate more than one possibility of interpretation in the scenarios? (probably, possibly, supposedly)
- 17 Are the condition terms (such as "if", "go to", "while") used correctly?
- 18 When you use words like "things" "data" in the scenario, do they have the same meaning in other parts of the same scenario?
- 19 Is it possible to identify "things" described with a function in the arrangements representing another function in the described scenarios?
- 20 Are the alternative and/or exception flows described?
- 21 Does the scenario specification identify the matching ID arrangement? (AII1, AII2, ..., AII9)

The second part (specific questions) considers the non-functional properties (IoT facets) of IoT software systems discussed in (Motta et al. 2019a). **Table 2** presents the questions of the second part of the SCENARI<sub>OT</sub>CHECK checklist.

Table 2. Questions on IoT Facets.

Nº	Question
24	Is it possible to identify the specific context in which the system is embedded? (Smart room, smart greenhouse, autonomous vehicle, healthcare, and so on)
25	Are the limitations of the environment described? (e.g., lack of connectivity structure, lack of hardware structure, inadequate infrastructure)
26	Are the technologies associated with system objects described? (smartphones, smartwatches, wearables)
27	Are the events that the system has identified? (e.g., on/off an object, sending data)
28	What kind of communication technology does the system use in the scenarios? (Bluetooth, intranet, internet ...)
29	Does the proposed communication technology meet the geographic/physical specifications of the system? (Large, medium or small scale)
30	Is it possible to identify how the system will react according to changes in the environment?
31	Are the interactions between the system and the environment represented in the scenarios?
32	Is it possible to identify the interaction between actors?

After specifying IoT scenarios, the inspectors can apply the SCENARI<sub>OT</sub>CHECK technique to verify the scenario descriptions. The identified non-conformities are described in the inspection report. Finally, after the discrimination meeting (defects identification), the IoT scenario specification document is corrected. The application process of the two techniques is shown in **Figure 2**.

The SCENARI<sub>OT</sub>CHECK complements SCENARI<sub>OT</sub> by providing a template for IoT scenarios specification. This template resembles a use-case description document with some additional fields: i) identification of the IoT software system elements; ii) problem domain description, iii) role description of each actor involved in the scenario;

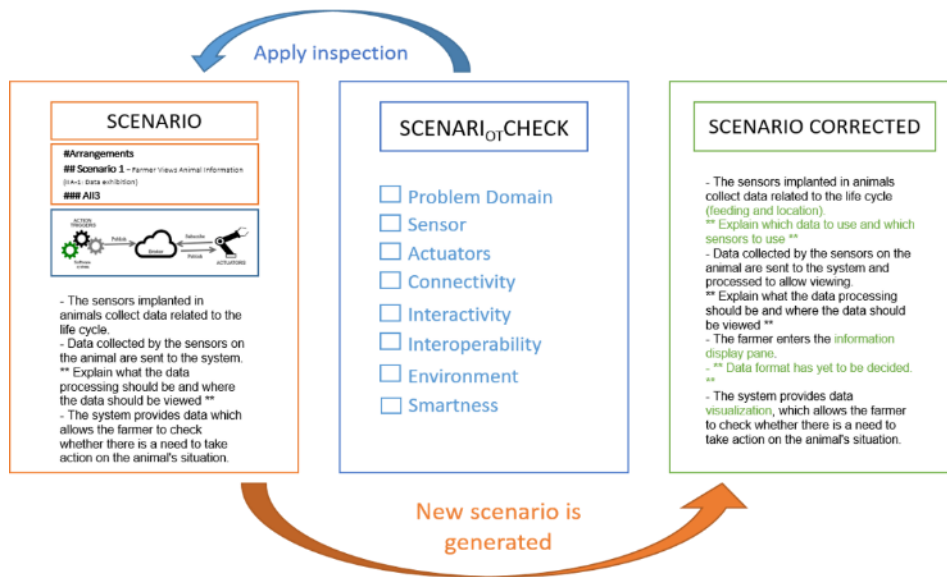


Figure 2. Application process of SCENARIoT and SCENARIoT CHECK techniques (Souza et al. 2019a).

and iv) descriptions of the interaction between the actors (end-user, things, software system, others) and the IoT software system.

### 3 The RET<sub>IoT</sub>

The RET<sub>IoT</sub> (Requirements Engineering Technology for the Internet of Things based software systems) comprises the techniques described in section 2, a construction process, and templates to build requirements document following RE principles.

The requirements document's construction process is based on the main RE phases (Pressman and Maxim 2014) (Sommerville 2015): conception/design, elicitation, analysis, specification, negotiation, verification, validation, and management. However, the RET<sub>IoT</sub> adapts and includes new activities to meet the specificities of IoT software systems.

#### 3.1 Construction process

The current version of the technology encompasses product ideation, evaluation concepts, such as low- and high-level prototypes, and MVPs' creation (Minimum Viable Product) for the desired product. In addition, the construction process incorporates aspects and characteristics found in the literature review inherent to IoT software systems.

It also involves the different RE phases (Pressman 2014) (Sommerville 2015) through an engineering cycle divided into four phases: **IoT ideation, conception, elicitation; IoT analysis and specification; IoT negotiation and evaluation; and Management.**

Figure 3 presents an overview of the construction process engineering cycle with two dimensions: **main** and **transversal** (performed in parallel). The main dimension corresponds to the activities and tasks required to build the IoT requirements document.

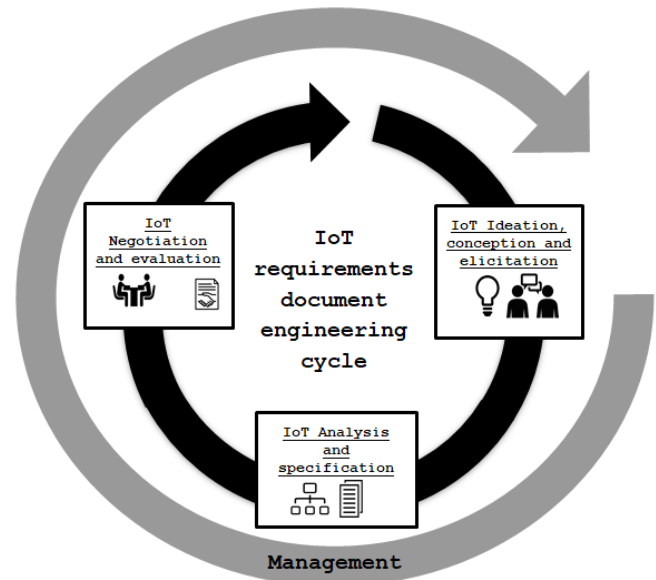


Figure 3. Construction process overview - phases.

The transversal dimension (see Figure 4) offers three management activities, and tasks focused on artifacts and process management. The activities and tasks do not have a specific and determined time to be performed. Instead, everything depends on the need identified by the user through the main process flow.

The technology proposes version control of the artifacts and traceability between requirements, IoT scenarios, IoT interaction arrangements, and IoT use cases in the management phase. Besides, RET<sub>IoT</sub> offers change management so that modifications in requirements can be reflected in the generated artifacts.

The IoT requirements document construction is performed iteratively and incrementally. Thus, the engineering cycle is executed three times, where each execution is called a **stage**.

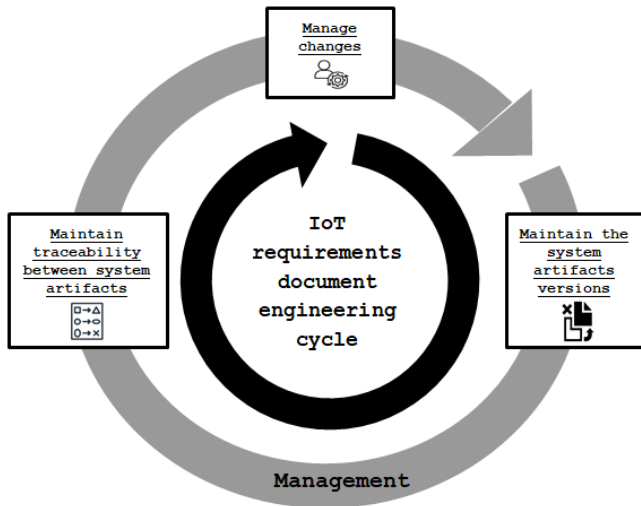


Figure 4. Management phase overview.

### 3.2 Construction process stages

Each stage performs the common phases (see Figure 3 and Figure 4) of the engineering cycle generating intermediate artifacts. The result of Stage 3 is the IoT requirements document. However, each stage has specific objectives, activities, and tasks. The construction process can be executed for one idea or a set of requirements (see Figure 5). In the first case, the process execution is an intermediated version of the IoT requirements document. Also, the construction process can be adapted to be used in different contexts. For example, we can apply this proposal with any development methodologies.

Regarding projects that use an agile methodology, IoT Use cases could be not applicable and demand more cost and effort. In these contexts, IoT Use cases cannot be mandatory, and the activities and tasks that support build them can be skipped. However, on the other hand, it can cause positive

impacts (decrease time and effort) and negative (absence of important information). Therefore, the user of the process needs to evaluate these impacts.

Besides, the current RET<sub>IoT</sub> version integrates ten templates – eight of them are defined/adapted from the project templates currently used in projects of the ESE group/PESC/COPPE and other templates used in software engineering group/PESC/COPPE. In addition, two of them were defined by the SCENARI<sub>IoT</sub>CHECK technique (Souza 2020).

Figure 6 shows an overview (IDEF0 diagram) of the three stages with their inputs, outputs, templates presented in the next paragraphs, and controls - Management procedures and Feasibility strategy. The Management phase performs the management procedures. The Feasibility strategy represents the milestone of each Stage.

#### 3.2.1 Stage 1

The first stage is to **understand the problem**. Then, it aims to understand the problem or opportunity, analyze the stakeholders and their needs, elicit the business needs, and carry out the project feasibility analysis. It is composed of 12 activities and 27 tasks that are distributed throughout the engineering cycle.

Figure 7 presents an overview of the activities performed in the first stage. This stage offers three templates: **IoT Canvas**, **IoT Project Feasibility Analysis**, and **Requirements Checklist**. Its milestone is the **Feasibility Analysis** performed by four activities (Analyze market demand, Analyze economic feasibility, Analyze impact and risks, and Analyze technical feasibility).

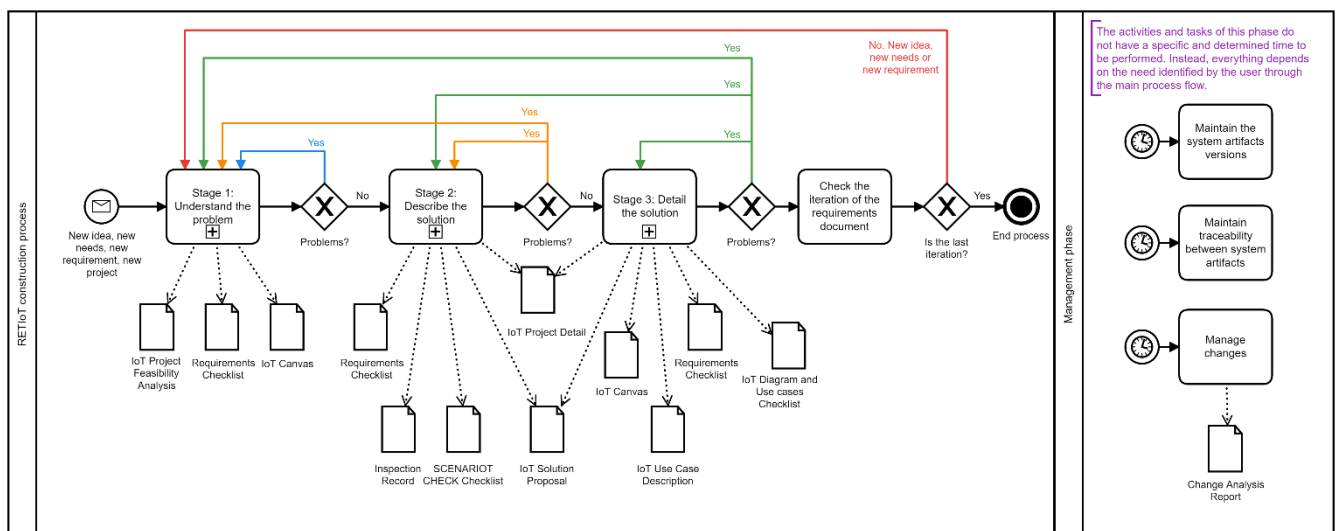


Figure 5. Construction process overview - stages

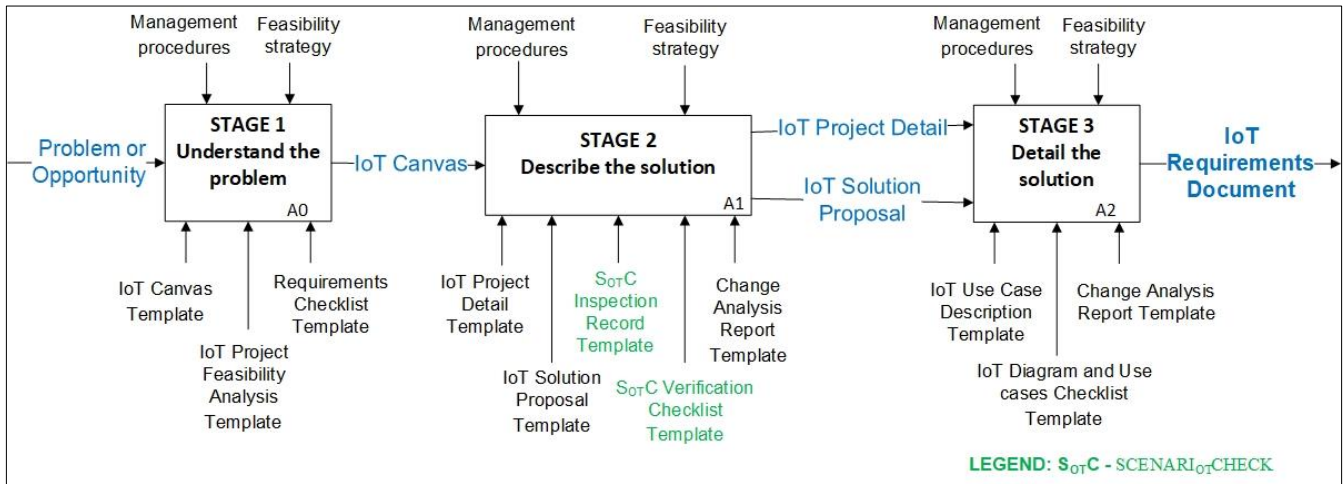


Figure 6. IDEFO diagram of the three stages

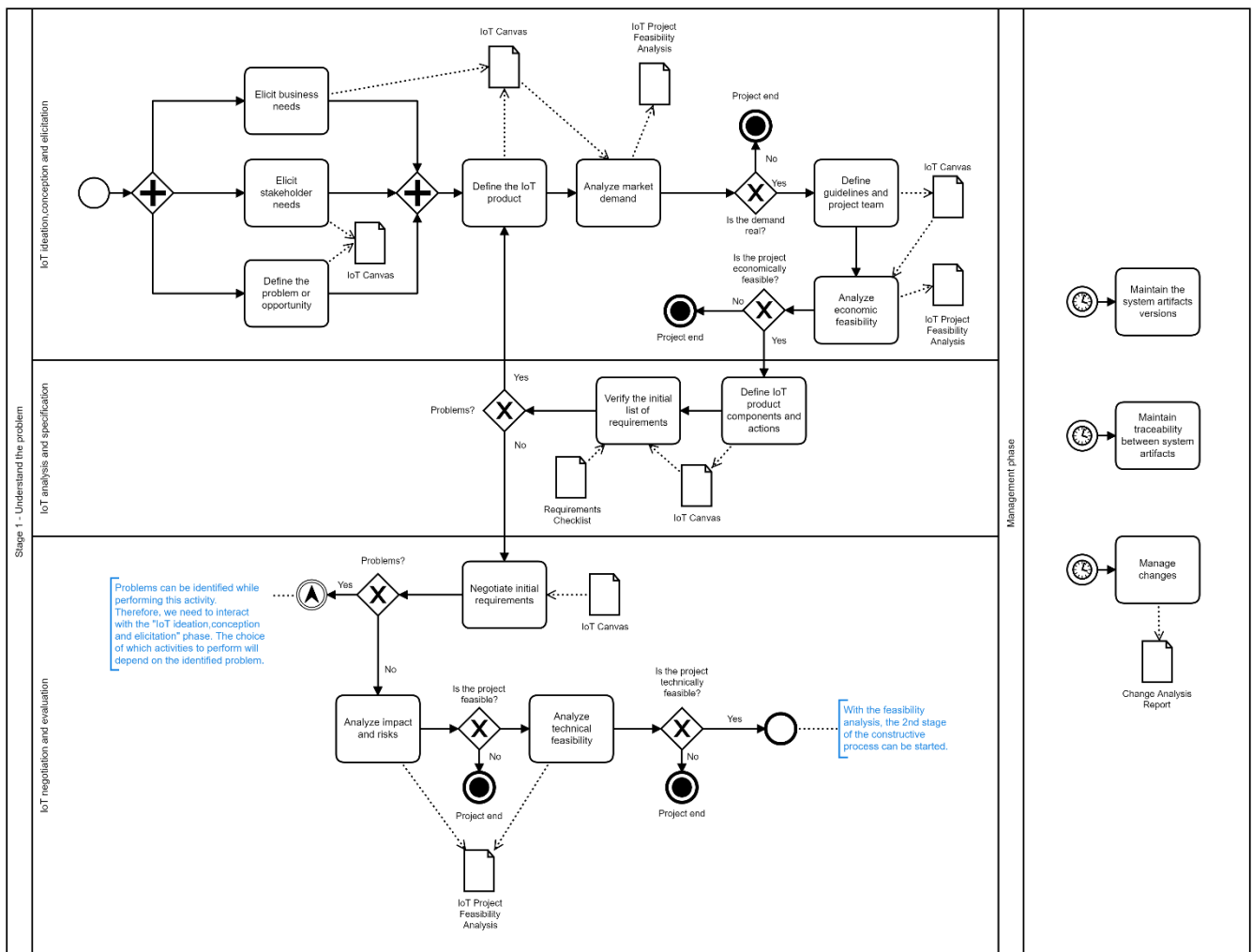


Figure 7. First stage - Overview of the construction process.

### 3.2.2 Stage 2

The second stage is to **describe the solution**. It aims to transform business needs, stakeholders' needs, and general requirements into detailed, classified, and organized requirements. IoT scenarios, arrangements, and components are used for the specification and verified during this stage.

Subsequently, the requirements are negotiated and evaluated, attesting that a common understanding of the system has been reached. This stage is composed of 12 activities and 39 tasks that are distributed throughout the engineering cycle.

The SCENARI<sub>IoT</sub> technique (Silva 2019) supports the requirements identification and the system behavior description. This technique is executed during the following activities: **Define IoT scenarios** and **Specify IoT scenarios**.

Figure 8 presents an overview of the activities performed in the second stage. This stage defines three templates: **IoT Project Detail**, **IoT Solution Proposal**, and **Change Analysis Report**.

The SCENARI<sub>IoT</sub>CHECK technique (Souza 2020) contributes with two templates (Verification Checklist Template and Inspection Record Template) used in this stage during **Verify IoT scenarios** activity.

Its milestone is the **Low-level Prototype** performed by the activity "Define low-fidelity prototype." This stage presents optional activities since the construction process can be used with any development methodology.

### 3.2.3 Stage 3

The third stage is to **Detail the solution**. It transforms IoT requirements and scenarios into IoT Use Cases. The IoT Use Cases diagram, the list of IoT Use Cases, and their descriptions are generated during this stage.

Subsequently, the generated artifacts are checked and evaluated, attesting that a common understanding of the system has been achieved. This stage is composed of ten activities and 24 tasks distributed throughout the engineering cycle.

Figure 9 presents an overview of the activities performed in the third stage. Two templates are defined for it: **IoT Use Case Description** and **IoT Diagram and Use cases Checklist**. Also, the **Change Analysis Report** can be used in this stage. This stage's milestone is the **High-level Prototype** performed by the activity "Define an evolved prototype." This stage presents optional activities since the construction process can be used with any development methodology.

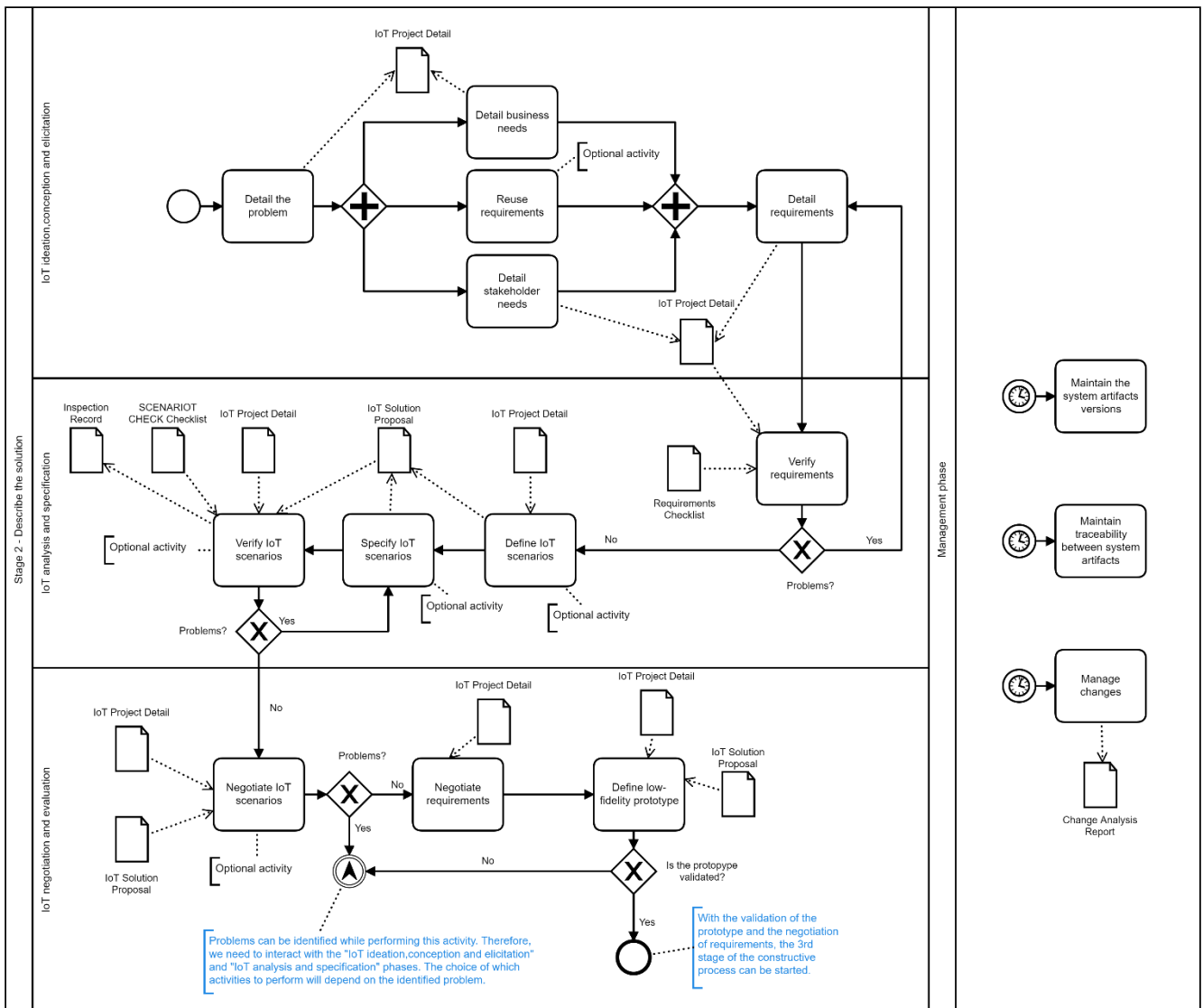


Figure 8. Second stage - Overview of the construction process.

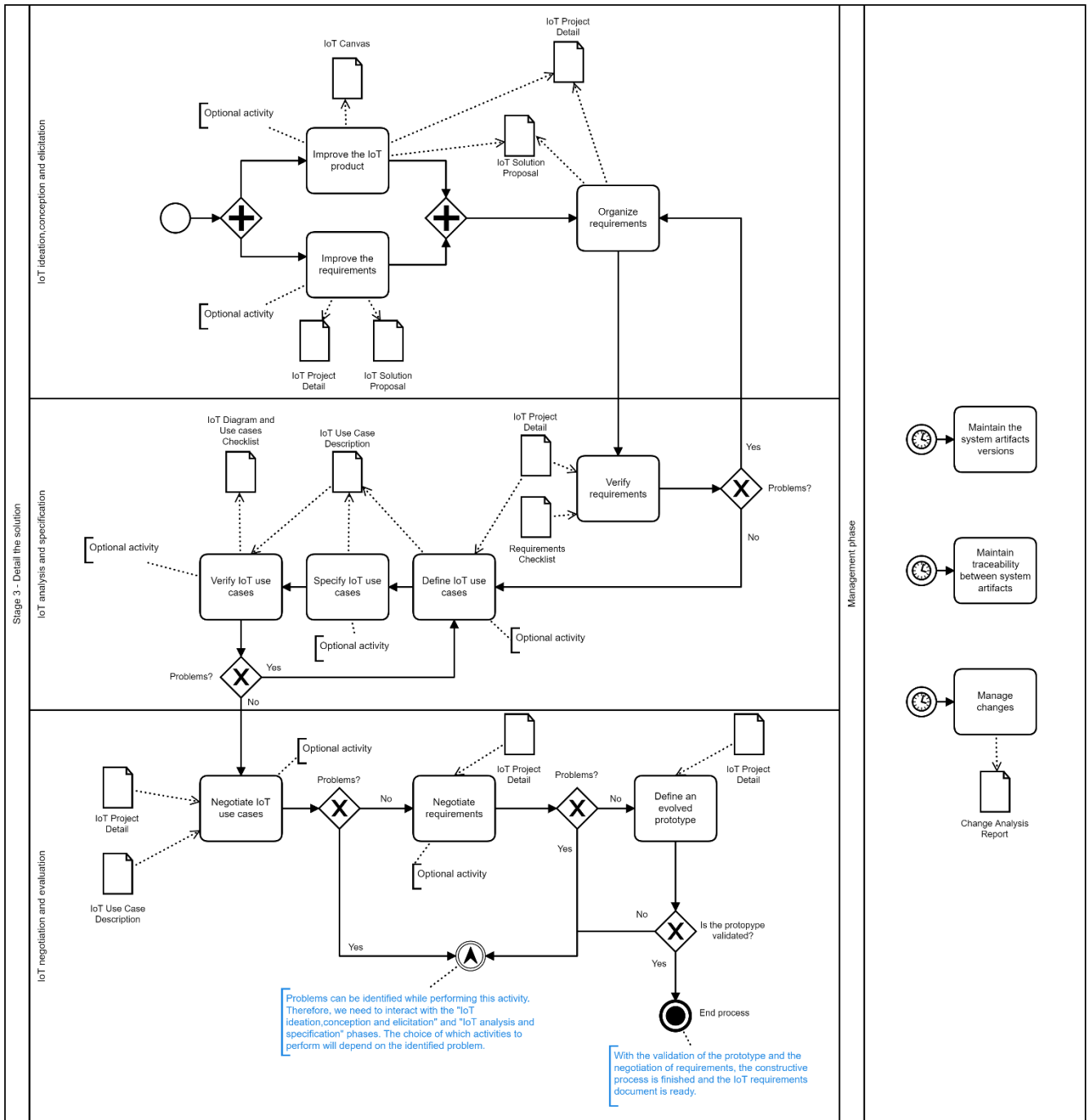


Figure 9. Third stage - Overview of the construction process.

## 4 Evaluating the RET<sub>IoT</sub>'s Templates Feasibility

The RET<sub>IoT</sub> aims to support software engineers during the RE activities. The main techniques presented in section 2 and used to compose the software technology have already been empirically evaluated and used in IoT software system projects (Souza et al. 2019a) (Souza et al. 2019b). However, new facilities' inclusion to support the RE with the RET<sub>IoT</sub> requires an initial observation before using them in the projects and conducting further experimental studies. Thus, this section presents a feasibility study of the RET<sub>IoT</sub> templates.

### 4.1 Templates

In this feasibility study, we considered the structure of two artifacts' templates – Requirements List (RL) and IoT use-cases Description (IoTUCD1) – for conventional software systems but used in IoT software system projects. We compared their structure with the structure of the RET<sub>IoT</sub> templates – Project Scope (PS), Solution Proposal (SP), and IoT use-cases Description (IoTUCD2). The full versions of all templates are available at <http://bit.ly/393SgHX>.



### 4.1.1 The RET<sub>IoT</sub> Templates

This section presents three RET<sub>IoT</sub> templates (Silva et al. 2020b) regarding the activities of **elicitation** (ELI) – "Project Scope (PS)" Template (see Figure 10); **analysis** (ANA) and **specification** (SPE) – "Solution Proposal (SP)" Template (see Figure 11) and "IoT use-cases Description (IoTUCD)" Template (see Figure 12). The **conception/design** (CON), **negotiation** (NEG), and **validation** (VAL) activities are minimally covered by the "Project scope" Template.

The "Solution Proposal" and "IoT use-cases Description" templates support the **management** (MAN) activities, maintaining traceability between requirements and analysis models. Besides, the techniques described in section 2 support the **elicitation** (ELI), **specification** (SPE), and **verification** (VER) activities. The following items will present the templates' global description (Project Scope, Solution Proposal, and IoT use-cases Description) as defined in the RET<sub>IoT</sub>.

- **Project Scope Template**

This template supports the documentation of the project's initial activities, the problem to be solved, those involved in the project, the user profiles, user needs, and business needs. In addition, it includes identifying and describing system requirements (functional, non-functional, restrictions, others) and business rules.

**Project Scope**

[describe what the system will do and its characteristics. Describe high-level modes or operating states, operational scenarios, potential use cases. Define the functional limit of the system or software element in terms of the behavior and properties provided. Highlight what the project does not intend to solve.]

**System Requirements**

**Functional Requirements**

ID	Description	Type	Situation	Priority
FR[id]	[requirement name or simple description]	[IoT or Classic]	[Proposed, Approved, Canceled]	[High, Medium, Low]
FR[id]	[requirement name or simple description]	[IoT or Classic]	[Proposed, Approved, Canceled]	[High, Medium, Low]
FR[id]	[requirement name or simple description]	[IoT or Classic]	[Proposed, Approved, Canceled]	[High, Medium, Low]

**Non-functional Requirements**

ID	Description	Situation	Priority

**Business Rules**

ID	Description	Situation	Priority
RN[id]	[name of business rule or simple description]	[Proposed, Approved, Canceled]	[High, Medium, Low]

Project Scope v 1.0

Figure 10. Extract from the "Project Scope template."

Also, the requirements document's validation is made through an explicit agreement (signature or email copy). Finally, it provides two (status and priority) fields to support the negotiation of functional and non-functional requirements.

Figure 10 presents an extract of this template. The proposed template is used in the activities of conception/design (CON), elicitation (ELI), negotiation (NEG), and validation (VAL).

- **Solution Proposal Template**

This template supports the solution description. It identifies and describes, using the SCENARI<sub>IoT</sub> technique, the IoT scenarios, the IoT components, and the IoT interaction arrangements (IIAs) of the system.

Also, it provides the details of the IIAs chosen for each IoT scenario via the corresponding catalogs. Thus, the traceability between requirements, IoT scenarios, IoT interaction arrangements, and their respective catalogs is maintained.

Figure 11 presents an extract of this template. It should be used in the elicitation (ELI), analysis (ANA), specification (SPE), and management (MAN) activities to identify, describe and refine the system's behavior while maintaining requirements traceability.

**Solution Proposal**

IoT ID	Title	Functional Requirement
IoT S[id]	[scenario title]	FR[id]

**IoT Arrangements Information**

[describe the information from the catalogs of the arrangements chosen previously in the tables below.]  
OBS. Just keep information on the chosen arrangements, that is, remove the catalog from the arrangements that are not part of the system. If the same chosen arrangement has more than one configuration, duplicate the catalog and fill in the respective information.

**Arrangement** IIA-1: Data exhibition

**Scenarios** [IoT S1, ..., IoT SN] and scenario title

**Arrangement Representation**

**Arrangement Catalog**

Component	Related Information	
Data Producers	Who collects data?	[e.g., sensors, tag readers]
	What type of data is collected?	[e.g., temperature, humidity, among others]
	Source of data	[e.g., rooms, cup of coffee, refrigerator, ground, among others]

Solution Proposal v 1.0

Figure 11. Extract from the "Solution Proposal template."

- **IoT use-cases Description Template**

This template includes the description of the IoT use-cases. Use cases are identified and described providing a view of the system's behavior. In addition, the use-case diagram is inserted in this template.

Traceability between requirements, IoT scenarios, IoT interaction arrangements, and IoT use-cases is maintained. Figure 12 presents an extract of this template. It should be

used in the analysis (ANA), specification (SPE), verification (VER), and management (MAN) activities.

The SCENARI<sub>OT</sub>CHECK technique is applied during the verification activities to identify inconsistencies in the IoT scenarios description and their components and the choice of IIAs.

IoT Use Cases Description				
IoT use case ID	Title	IoT Requirements	Interaction Arrangements	IoT Scenarios
IoT UC[id]	[use case title]	[FR01, ..., FRN]	[IIA-01, ..., IIA-09]	[IoT S01, ..., IoT SN]
IoT Use Case Diagram				
[insert image representing the use cases present in the system to be built.]				
IoT Use Case Detail				
[detail IoT use case information from the IoT scenarios identified above.]				
Use Case ID	IoT UC[id]	Use Case Title	[use case title]	
IoT Interaction Arrangements	[IIA-01, ..., IIA-09] and name of the arrangement			
Preconditions	[describe the initial conditions for executing the use case]			
Postconditions	[describe the final conditions after the use case is executed]			
Associated Use Cases	[IoT UC-01, ..., IoT UC-N]			
Actors	Users: [describe users as: end user, animals ...]			
	Things: [describe the things, sensors, wearables, and so on]			
	Software systems: [describe the machines and software systems here]			
Interaction Sequence				
[describe the steps of this scenario using the actors described above and their respective interactions in the arrangement]. OBS: Collection and processing of data should also be considered. Remember, the scenarios need to be objective and clearly understood.				
Steps	BASE FLOW [describe the main flow of the use case].			
	ALTERNATIVE FLOW [describe the scenario's alternative flows].			
	EXCEPTION FLOW [describe the scenario's exception flows].			
	BUSINESS RULES [describes the scenario's business rules].			

IoT Use Case Description v 1.0

Figure 12. Extract from the "IoT use-cases Description template."

### 4.1.2 Projects and Teams

The RL and IoTUCD1 artifacts were built by using conventional templates in three (3) IoT based software projects:

- **Project A** supports environmental markers' collection (e.g., temperature, humidity, particulates, CO<sub>2</sub> level, and toxic gases).
- **Project B** monitors a high-performance computing environment (data center) to collect different information such as temperature, humidity, energy consumption, and energy supply quality.
- **Project C** collects temperature, humidity, wind speed, and wind direction in different city regions.

All three projects represent real demand. A stakeholder (totally external to the course and the research group) worked with the developers, including the requirements acceptance. Undergraduate students produced the RL and IoTUCD1 artifacts during a Software Engineering course at UFRJ. The course had the participation of 21 students of the fourth year of Information and Computer Engineering.

The subjects were organized into three development teams, with seven participants each. The teams contained

balanced participants with equivalent levels of knowledge and skills regarding software and hardware. Training on different topics in Software Engineering and mentoring throughout the project were available. There was no intervention by the mentors in the artifact's content. All ethical issues and consent forms were made available.

Some of the course's topics included requirements engineering, IoT scenarios, verification technique for IoT systems, UML (Unified Modeling Language) diagrams, among others. In addition, the SCENARI<sub>OT</sub> and SCENARI<sub>OT</sub>CHECK techniques were presented to the participants, although they were not conditioned to use them.

The teams were free to organize their projects. The requirements document represented one of the design milestones. A minimum viable product (MVP) represents one of the concrete results delivered at the end of the course.

## 4.2 Execution

The researchers (paper's authors) analyzed the requirements document (RL and IoTUCD1 artifacts) after the three teams constructed them.

The information found in the generated artifacts was compared with the requested information in the Project Scope (PS), Solution Proposal (SP), and IoT use-cases Description (IoTUCD2) templates structure. A working checklist was used to compare the templates, which will be presented in the next subsection.

Three researchers carried out the comparison – two master's students and one Ph.D. that work in Software Engineering and IoT domains. After that, a fourth researcher (Ph.D. and expert in Software Engineering and IoT domains) reviewed the analysis of the results.

## 4.3 Results and Discussion

Table 3 presents the checklist used to compare the template structure (conventional and RET<sub>IoT</sub>) and the analysis result. It indicates that:

- The RL template does not address the project/system objective and problem domain. However, knowing the problem domain is essential for building an IoT software system (Motta et al. 2019) (Nguyen-Duc et al., 2019).
- The RL template presents a partial description of the stakeholders. However, it does not include profiles descriptions of the different users important for the system development and the user interface design.
- The RL template does not address the description of business/stakeholder needs. The identification of business/stakeholder needs represents the initial stage of the project. In this step, we seek to understand the client's real need, which will be transformed into system requirements in the future.
- RET<sub>IoT</sub> allows identifying the requirements that will guide the IoT solution from the beginning (Project Scope template), unlike the RL template that does not identify the IoT requirements.

Table 3. Mapping checklist of the template structure.

Project/system information	Conventional templates		RET <sub>IoT</sub> templates		
	RL	IoTUCD2	PS	SP	IoTUCD2
Project name/Project responsible	T	T	T	T	T
Version control	T	T	T	T	T
Explicit agreement	T	Gray	T	Gray	Gray
Project/system objective	N	Gray	T	Gray	Gray
Problem domain	N	Gray	T	Gray	Gray
Project scope	T	Gray	T	Gray	Gray
Glossaire	T	Gray	T	Gray	Gray
Stakeholders description	P	Gray	T	Gray	Gray
Business and Stakeholders needs a description	N	Gray	T	Gray	Gray
Functional requirements	P	Gray	T	Gray	Gray
Non-functional requirements	T	Gray	T	Gray	Gray
Requirements negotiation (prioritization)	T	Gray	T	Gray	Gray
Business rules	N	T	T	Gray	T
Project analyses	N	Gray	P	Gray	Gray
IoT scenarios	Gray	P	Gray	T	Gray
IoT components description	Gray	N	Gray	T	T
IoT interaction arrangements	Gray	P	Gray	T	T
IoT use-cases diagram	Gray	N	Gray	Gray	T
IoT use-cases description	Gray	N	Gray	Gray	T
Requirements traceability	Gray	P	-	P	T
References (others project documents)	T	Gray	N	Gray	Gray

P - Partially collected; T - Totally collected; N - Does not collect information; Gray - Not applicable for this template.

- The IoTUCD1 template treats IoT scenarios and IoT arrangements partially but does not address IoT components' description. In contrast, the RET<sub>IoT</sub> treats this information entirely in the Solution Proposal (SP) and IoT use-cases Description (IoTUCD 2) templates.
- Conventional templates are not treat the IoT use-cases diagram and IoT use-cases description, but RET<sub>IoT</sub> fully treats them.
- The requirements traceability is partially treated by the IoTUCD1 template, partially treated by RET<sub>IoT</sub> in SP template, and fully treated IoTUCD2 template.
- The RL template presents a field for references (other documents), which RET<sub>IoT</sub> does not address.

The different convergence and divergence points between conventional systems templates (RL and IoTUCD1) and RET<sub>IoT</sub> templates (PS, SP, IoTUCD2) offer indications that the RET<sub>IoT</sub> can be more robust because it deals with IoT information since the beginning of the project

According to the results, RET<sub>IoT</sub> can present (Silva et al. 2020a) (Silva et al. 2020b) a good potential for supporting IoT software systems' specifications because of its templates' specific IoT information, differently from conventional ones.

#### 4.4 Templates' evolution

This study allowed us to evolve the existing templates regarding the reorganization of sections and insert new sections and new fields. First, we identified the lack of information and redundancies on templates. Then some fields were added, moved, or removed. Besides that, we started to think about MVP and prototypes applied on IoT projects that caused changes in some templates, and we added the "IoT Canvas" template to the technology.

In the second version, we started to think about requirements negotiation, reuse, and traceability. Consequently, we

identified the need to insert new fields to attend to these points better. Also, the templates of the second version did not cover the project feasibility and requirements verification. It is because the technology does not cover these points.

To fill these gaps, we propose "Project Feasibility Analysis," "Requirements Checklist," and "IoT Diagram and Use cases Checklist" templates. At least, we identified the need to register and track requirements changes. The second version presented activities and tasks to support it, but no template was defined. In that sense, one more template, named "Change Analysis Report," was defined to support these activities. In addition, the **Project Scope** template was renamed to **IoT Project Detail** and the **Solution Proposal** template to **IoT Solution Proposal**.

In the **IoT Project Detail** template, we included a new field, "Project description." The "Glossary" and "Stakeholders" sections have been changed to include fields to support the capturing of specific information. The "Potential stakeholders" section has been changed to "Stakeholders" to include two new fields to capture each stakeholder's interest and its influence in the system. The "Project scope" section has been removed from the template. The "Canvas IoT" section was added, allowing the insertion of an image or photo of the IoT Canvas built in Stage 1.

New fields ("Reused requirement?" and "Related requirement ID") have been added to the "System requirements" section to enable requirements traceability (functional and non-functional). In addition, for functional requirements, two fields ("Cost" and "Effort") were added to make negotiation feasible. In its previous version, requirements were classified into IoT requirements and non-IoT requirements. In this new version, this classification has been removed, and the "IoT Characteristic" field has been included. Therefore, when describing a non-IoT requirement, this field should not be filled. Instead, the IoT characteristic must be described as identification, sensing, performance, connectivity, and processing in an IoT requirement. In addition, the "Dependency

between requirements" field has also been added to the "Functional requirements" section.

The non-functional requirement "scalability" was added to the new template. The requirements "portability and compatibility" and "security and privacy" have been adapted. The section "Annex - Non-functional requirements" has been added to support the identification of non-functional requirements. The section "Scope not covered by the project" has been added, and the section "Project analysis" has been removed. In the "Business rules" section, the "Related needs ID" field has been added to allow business rules' traceability.

In the **IoT Solution Proposal** template, the fields "Actors," "Actions," "Interaction Arrangements" were added in the "IoT Scenarios" section. The section "IoT system components" was removed because it had a redundancy of the arrangement catalogs' information. The "Related functional requirements," "Precedencies," and "Dependencies" fields have been added in the "IoT scenarios description" section to enable the traceability of IoT scenarios. The field "Collected data and Actions performed" was divided into two fields: "Collected data" and "Actions performed." The "Interaction sequence" field was changed because it is like a use-case structure (main, alternative, and exception flows). Finally, the "Environment" and "Connectivity" fields have been removed.

In the **IoT use-cases Description** template, the "Business rules" field was moved from the "Interaction sequence" section to a separate section. In addition, the section "Customer or customer representative agreement" has been added to this template.

Five new templates were also defined to support the construction process activities that had not yet been contemplated. The new models (see section 3) correspond to **IoT Canvas**, **IoT Project Feasibility Analysis**, **Requirements Checklist**, **Change Analysis Report**, and **IoT Diagram and Use cases Checklist**.

Table 4 shows each change and the rationale for them.

However, to ensure the technology validity, further experimental evaluation is necessary to verify whether the RET<sub>IoT</sub> construction process with the templates is useful, complete, correct, and intuitive.

### 4.5 Threats to Validity

**Internal validity** is the study itself, even though experimental studies have evaluated part of the RET<sub>IoT</sub> technology. However, the results indicate that the RET<sub>IoT</sub> templates can capture relevant information than conventional templates regarding project artifacts.

An **external validity** issue concerns the participants (undergraduate students) who have been invited to participate in the study. We cannot claim that the information provided is complete from the project's point of view, nor did the participants understand all the topics taught during the course. To mitigate this threat, the projects treated in the study represented real problems. Besides, each team had contact with a stakeholder of each addressed problem.

There was no control over the artifact's creation during the course and used in the study regarding their construct valid-

ity. However, the projects were equivalent in size, complexity and used IoT technologies to mitigate this threat. Also, it can be highlighted that the teams received equivalent training and mentoring in RE.

Finally, the **conclusion validity** concerns the study interpretation and sample size. We had a small and inhomogeneous sample size. Therefore, it was impossible to apply statistical tests to carry out a deeper analysis of the results obtained. Also, the study conclusion is limited to the researchers' interpretation. These items limit the study results generalization. To mitigate this threat, we aim to perform future experimental studies to collect feedback from the RET<sub>IoT</sub>.

## 5 Literature analysis

### 5.1 RE phases

This section presents related works found in the technical literature, which address technologies for the different RE phases mentioned above. Table 5 presents a comparison of seventeen (17) technologies found in the technical literature. We can observe that conception, negotiation, verification, validation, and management phases need more attention regarding IoT concepts and characteristics.

Figure 13 synthesizes the information presented in Table 5, showing the number of technologies per RE phase. Again, we can highlight that a high number permeate elicitation (nine), analysis (ten), and specification (eight) phases. In contrast, a small number is concentrated in the conception/design (four), negotiation (one), verification (five), validation (three) and management (three) phases.

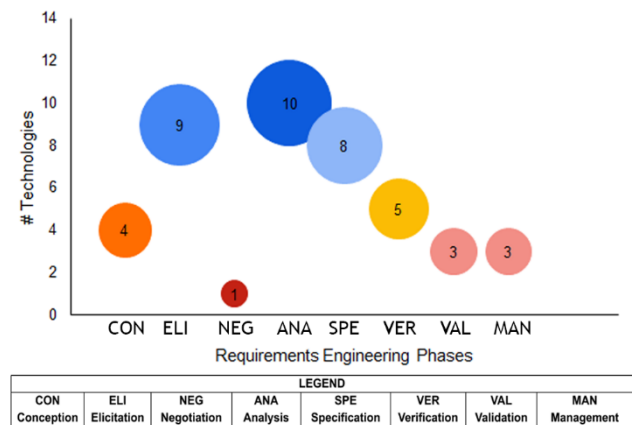


Figure 13. Technologies x RE phases.

Regarding the **conception phase** (CON), GSEM-IoT (Zambonelli 2017) (Laplante et al. 2018) and Ignite (Giray et al. 2018) technologies carry out the stakeholders' analysis involved in the system. In addition, the feasibility analysis is partially addressed by IoT Methodology (Giray et al., 2018). Also, the Ignite and CORE (Hamdi et al. 2019) technologies provide business analysis mechanisms.

**Table 4.** Templates' evolution.

Template name	Previous element	New element	Change description	Rationale
IoT Project Detail	-	Project description.	Included new field	Allow getting a simple and brief description of the project.
	Glossary and Stakeholders	-	Included fields to support the capturing of specific information	Enable to capture specific information about terms used in the project and stakeholders.
	Potential stakeholders	Stakeholders	Change section name and included two new fields to capture interest and influence	Simplify this section and capture more data about the stakeholders.
	Project scope	-	Removed from the template	Allows avoiding redundancy. The described requirements can identify the project scope.
	-	Canvas IoT	Included new field	Allow the insertion of an image or photo of the IoT Canvas built in Stage 1
	-	Reused requirement? And Related requirement ID	Included new field added to "System requirements" section	Enable requirements' reuse and traceability.
	-	Cost and Effort	Included new field	Make negotiation feasible.
	IoT requirements and non-IoT requirements	IoT Characteristic (only to IoT requirements)	This classification has been removed, and the "IoT Characteristic" field has been included	Simplify this section and enable to capture identification, sensing, performance, connectivity, and processing characteristics on requirements.
	-	Dependency between requirements	This field has also been added to the "Functional requirements" section	Enable requirements' traceability.
	-	Non-functional requirements "scalability", "portability and compatibility" and "security and privacy"	The section has been improved	This field's description of this section has been adapted and improved to attend IoT systems better.
Project analysis	-	Annex - Non-functional requirements	Included new section	Support the identification of non-functional requirements.
	-	Scope not covered by the project	Included new section	Enable to capture and describe the
	-	-	The section has been moved to another template	A new template (IoT Project Feasibility Analysis) has been created. As a result, the information presented in this section has been adapted and moved to a specialist template.
	-	Related needs ID	A new field has been added to the "Business rules" section	Allow business rules' traceability.
IoT Solution Proposal	-	Actors, Actions, and Interaction Arrangements	Included new field added in the "IoT Scenarios" section	Enable traceability between IoT Scenarios information.
	IoT system components	-	This section has been removed	Avoid redundancy of the arrangement catalogs' information.
	-	Related functional Requirements, Precedencies and Dependencies	Included new fields have been added in the "IoT scenarios description."	Enable traceability between IoT scenarios.
	Collected data and Actions performed	Collected data and Actions performed	The field "Collected data and Actions performed" was divided into two fields	Simplify this section and separate specific information.
Interaction sequence	-	Remove alternative and exception flows.	Simplify this section because it is like a use-case structure (main, alternative, and exception flows).	
Environment and Connectivity	-	These sections have been removed	Simplify this section. We believe this information is not relevant at this point. In this way, they must be collected during the design projects' phase.	
IoT use-cases Description	Business rules	-	The business rules field was moved from the "Interaction sequence" section to a separate section	Simplify this section.
	-	Customer or customer representative agreement	This section has been added	Enable to get an explicit agreement about IoT Diagram and Use cases.
IoT Canvas	-	-	This template has been added	Enable to support projects' description and idea validation through the easy and fast way.

Template name	Previous element	New element	Change description	Rationale
IoT Project Feasibility Analysis	-	-	This template has been added	Enable to support projects' decision-making about feasibility in market demand, cost, impact, risks, and technology.
Requirements Checklist	-	-	This template has been added	Enable to verify if requirements are correct, understandable, and consistent.
Change Analysis Report	-	-	This template has been added	Enable to manage requirements' change through the project life cycle.
IoT Diagram and Use cases Checklist	-	-	This template has been added	Enable to verify if IoT Diagram and Use cases are correct, understandable, and consistent.

**Table 5.** Technologies x RE phases.

Technology/RE Phase	CON	ELI	NEG	ANA	SPE	VER	VAL	MAN
(Aziz et al. 2016)				x	x			x
(Mahalank et al. 2016)					x			
(Takeda and Hatakeyama 2016)				x	x			
(Touzani and Ponsard 2016)				x				
IoT-RML (Costa et al. 2017)				x	x	x		
(Yamakami 2017)						x		
GSEM-IoT (Zambonelli 2017)	x	x						
(Carvalho et al. 2018)						x		
(Curumsing et al. 2019)		x		x		x		x
IoT System Development Methods								
Ignite (Giray et al. 2018)	x	x	x	x	x		x	
IoT Methodology (Giray et al. 2018)	x	x					x	
(Laplante et al. 2018)	x	x		x			x	
IoTReq (Reggio 2018)		x		x	x			
CORE (Hamdi et al. 2019)		x		x				
SCENARI <sub>OT</sub> (Silva 2019)		x		x	x			
SCENARI <sub>OT</sub> CHECK (Souza 2020)						x		
TrUStAPIS (Ferraris and Fernandez-Gago 2020)		x			x			x

Several technologies address the **elicitation phase** (ELI): Ignite (Giray et al. 2018), IoT Methodology (Giray et al. 2018), (Laplante et al. 2018), IoTReq (Reggio 2018), (Curumsing et al. 2019), CORE (Hamdi et al. 2019), SCENARI<sub>OT</sub> (Silva 2019) and TrUStAPIS (Ferraris and Fernandez-Gago 2020) that offer resources for collecting requirements. In addition, GSEM-IoT (Zambonelli 2017), IoTReq, and IoT Methodology propose mechanisms to transform users' needs into requirements.

For the **negotiation phase** (NEG), Ignite (Giray et al., 2018) addresses the impact and risk analysis but does not provide further details on conducting this activity.

In the **analysis phase** (ANA), (Takeda and Hatakeyama 2016) and (Touzani and Ponsard 2016) technologies, Ignite (Giray et al. 2018), (Laplante et al. 2018), IoTReq (Reggio 2018), (Curumsing et al. 2019) and CORE (Hamdi et al. 2019) use UML diagrams to develop the analysis models. The SCENARI<sub>OT</sub> technology (Silva 2019) comprises the scenario analysis based on IoT interaction arrangements. The works of (Aziz et al. 2016) and IoT-RML (Costa et al., 2017) address artifacts and models' reuse.

The **specification phase** (SPE) is addressed by several technologies: (Takeda and Hatakeyama 2016), IoT-RML (Costa et al. 2017), IoTReq (Reggio 2018), and TrUStAPIS (Ferraris and Fernandez-Gago 2020) that use formal models for specifying requirements. Technologies proposed by (Aziz et al. 2016), (Mahalank et al. 2016), and (Giray et al. 2018) – Ignite provide templates for specifying requirements. The SCENARI<sub>OT</sub> (Silva 2019) proposes the scenario specification using IoT interaction arrangements.

In the **verification phase** (VER), we found that (Carvalho et al. 2018) and SCENARI<sub>OT</sub>CHECK (Souza 2020) propose mechanisms to verify requirements. The technologies proposed by (Yamakami 2017), (Costa et al. 2017) – IoT-RML (Carvalho et al., 2018), and (Curumsing et al. 2019) offer mechanisms for checking conflicts between requirements.

The **validation phase** (VAL) is addressed by Ignite (Giray et al., 2018), IoT Methodology (Giray et al., 2018), and (Laplante et al., 2018), which propose a prototyping technique to ensure that the product meets users' needs.

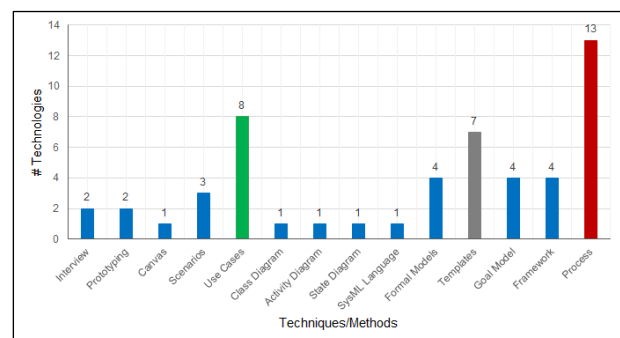
For the **management phase** (GER), (Aziz et al. 2016), (Curumsing et al. 2019), and TrUStAPIS (Ferraris and Fernandez-Gago 2020) offer mechanisms to enable traceability. In addition, TrUStAPIS also provides a mechanism for requirements change management.

## 5.2 Techniques and methods

A quasi-systematic literature review (Lim et al. 2018) identified 12 relevant publications and 37 elicitation techniques normally applied in IoT systems development. The most frequently used techniques are **interviews** and **prototypes**, where the latter can also be used to validate requirements.

We can also highlight other techniques and methods applied during the elicitation phase: scenarios, use cases, and frameworks. This work also presents a brief contribution regarding the conflict resolution of the stakeholders. The authors emphasize using interview and prototyping techniques to encourage discussions and find alternative ways to identify conflicts.

In this way, we analyzed the 17 technologies to identify which techniques/methods are used and where (RE phases) in IoT systems development. **Figure 14** shows our findings where we can observe 14 items and the most used: process (thirteen), use cases (eight), and models (seven).

**Figure 14.** Technologies x Techniques/Methods.

**Table 6** shows where (RE phases) the techniques/methods found are applied. The elicitation (28), analysis (30), and specification (22) phases offer a greater number of tech-

niques/methods. It is important to highlight that some technologies offer more than one technique for one or more RE phases.

RET<sub>IoT</sub> permeates the eight phases previously described offering methodological and technical support through construction, techniques, and templates.

Analyzing the RET<sub>IoT</sub> current version (see section 3), we can say that it proposes and integrates some techniques/methods: prototyping, IoT canvas, IoT scenarios based on IoT scenarios specification technique - SCENAR-<sub>IoT</sub> (Silva 2019), use cases diagram and description, templates, and IoT scenario inspection technique - SCENAR-<sub>IoT</sub>CHECK (Souza 2020), and a construction process.

## 6 Research Opportunities

Analyzing the technologies found in the technical literature, we can observe that only one technology discusses the **Negotiation phase**. It represents a research opportunity. Few technologies offer project management, validation, test case elaboration, and decision-making related to the system's design and architecture. These topics can be explored through future research. We can also observe that not all technologies cover all RE activities and present gaps regarding the different activities necessary to build IoT system requirements document.

Among these gaps, we can observe the lack of i) methodological support for the design and ideation of IoT products (Nguyen-Duc et al. 2019); ii) stakeholder identification and description and business needs (Silva et al. 2020b); iii) IoT

system characteristics and behaviors (Motta et al. 2019a), as well as the requirements refinement; iv) high-level (new IoT interaction arrangements) and low-level (IoT use-case diagram) analysis models; v) project feasibility analysis (Silva et al. 2020); vi) prototypes as suggested by (Nguyen-Duc et al. 2019) (Lim et al. 2018); and vii) explicit agreements with the client (Silva et al. 2020).

These technologies also do not fully meet the IoT software system specificities and characteristics: i) the components and actors' description (Curumsing et al. 2019) (Aziz et al. 2016); ii) the behaviors description of different levels of each object - (Curumsing et al. 2019) (Reggio 2018); iii) the identification of the systemic characteristics (sensing, identification, performance, processing, and connectivity); and iv) the detailed specification of each feature.

## 7 Conclusion and Future Works

This paper presented the RET<sub>IoT</sub>. It provides a construction process, techniques (IoT scenario specification and verification techniques), and tools (templates) to support IoT software's Requirements Engineering systems. Besides, this work seeks to accomplish an initial observation about this technology that focuses on analyzing and evaluating only the templates. A feasibility study was performed to compare three templates defined in the second version of RET<sub>IoT</sub> with conventional software systems templates (not specific to IoT software systems). Their comparison provided indications that the artifacts generated by RET<sub>IoT</sub> may be complete regarding the capture of IoT information.

**Table 6.** Techniques/Methods x RE phases.

Techniques-Methods /RE Phase	CON	ELI	NEG	ANA	SPE	VER	VAL	MAN
Interview		2						
Prototyping							3	
Canvas		1					1	
Scenarios		1			3			
Use cases	2	2		7	1			
Class Diagram				1				
Activity Diagram				1				
State Diagram				1				
SysML Language				1	1	1		
Formal Models		2		4	2	1		1
Templates	2	3			5	1		2
Goal model		2		4	1			1
Framework	2	3	1	2	1		2	
Catalogs		1			1	1		
Process	3	11	1	9	7	3	3	3
Total	9	28	2	30	22	7	9	7

The experimental study was planned to analyze the process and templates of RET<sub>IoT</sub>. However, it was not possible to conduct this study due to COVID 19 pandemic. Some of the future work reserved for the RET<sub>IoT</sub> are: i) (re)design and execution of experimental studies to evaluate the technology in more robust IoT software system projects (both academic and industrial contexts); A comparative study of the RET<sub>IoT</sub> with traditional technologies will be carried out to verify the efficiency and effectiveness of the RET<sub>IoT</sub> in terms of capturing system and project relevant information. Such a study should also evaluate the RET<sub>IoT</sub> usefulness and suitability according to the user's perception; ii) integrating RET<sub>IoT</sub> with a testing technique to support software engineers with the

specification of context-aware test cases - CATS# Context-Aware Test Suite Design (Doreste and Travassos 2020); and iii) developing tooling support integrating the construction process, IoT scenario specification, and verification techniques templates. The tool will facilitate the traceability among IoT requirements, IoT Interaction Arrangements, IoT scenarios, and IoT use-cases.



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