Evaluation of Non-Functional Requirements for IoT Applications

Joseane O. V. Paiva[a], Rossana M. C. Andrade[b] and Rainara Maia Carvalho[c]
Group of Computer Network, Software Engineering and Systems, Federal University of Ceará, Fortaleza, Brazil

Keywords: Internet of Things, Software Quality, Non-Functional Requirements, Systematic Mapping.

Abstract: Internet of Things (IoT) is a paradigm that enables physical objects to interact and to work together. IoT applications have particular characteristics, such as context-awareness, interconnectivity, and heterogeneity, and particular types of interaction, user interaction with devices (called human-thing interaction), and the interaction between devices (called thing-thing interaction). These characteristics represent the expectation around the system and are also known as Non-Functional Requirements (NFRs). So, during the requirements elicitation of such systems, they can appear as NFRs, and their combination often increases the complexity of the IoT application development and evaluation. Thus, this work aims to identify which approaches and NFRs have been considered in the literature to evaluate IoT applications and the main challenges faced by the evaluators. We use the systematic mapping methodology to provide a comprehensive view of approaches, methods, tools, and processes. As a result, we identified two tools, six approaches, one method, and one process that can be used to evaluate NFRs, a set of 42 NFRs that can be considered for IoT applications, and the main challenges related to the NFRs evaluation for the IoT applications.

1 INTRODUCTION

Internet of Things (IoT) can be defined as a paradigm where intelligent objects interact in an environment through a wireless connection, being able to cooperate to provide services and to achieve common goals (Atzori et al., 2010).

IoT applications are increasingly present in our daily lives, on the streets, in the malls, at work, or in our homes (Rowland et al., 2015). Users have been adapted themselves to the presence of devices that, through sensors, capture data about their environment, their health, their behavior, and learned to use the facilities provided by these solutions.

The growing presence around us of intelligent objects or things like *smartphones*, *smartwatches*, intelligent lamps, among others, shows that IoT has become a reality in our lives, being it in the industrial or personal context.

On the other hand, the way users interact with these solutions may differ from how s/he interacts with traditional applications.

IoT applications deal with countless other forms of interactions such as gestures, vocal commands, or the total absence of user actions (Rowland et al., 2015).

Besides the user interaction with devices (i.e., Human-Thing Interaction), IoT applications present a new type of interaction, the Thing-Thing Interaction, which is the interaction between intelligent objects. The connected devices relate without human intervention to perform a task (Andrade et al., 2017).

Moreover, IoT applications have particular characteristics, such as context-awareness, interconnectivity, and heterogeneity, that should be considered in the requirements elicitation and evaluation.

In this scenario, due to the inherent complexity of IoT applications, the traditional evaluation methods available in the literature may not cover all the quality properties that need to be considered. These quality properties or attributes are also known as non-functional requirements (NFRs) (Uckelmann et al., 2011).

NFRs can be defined as a description of a property or characteristic that a system must exhibit or a constraint that it must respect (Wiegers and Beatty, 2013).

Meeting the chosen NFRs is vital to the success of the software (Chung and Prado Leite, 2009). However, ensuring that the system meets NFRs is not a trivial task and there is a need to find out how NFRs

[a] https://orcid.org/0000-0003-1700-8765
[b] https://orcid.org/0000-0002-0186-2994
[c] https://orcid.org/0000-0002-4806-0542

Paiva, J., Andrade, R. and Carvalho, R.
Evaluation of Non-Functional Requirements for IoT Applications.
DOI: 10.5220/0010461901110119
In *Proceedings of the 23rd International Conference on Enterprise Information Systems (ICEIS 2021) - Volume 2*, pages 111-119
ISBN: 978-989-758-509-8

of IoT applications have been evaluated.

Quality evaluation for IoT applications is a topic that has received attention from the scientific community. Kim (2016), for example, proposed a quality model for IoT applications and specific measures for this type of application.

Andrade et al. (2017) discuss how we can benefit from the ubiquitous field of systems interaction evaluation to evaluate interaction with IoT applications, focusing on both systems' main differences and similarities and, Bures et al. (2020) present a set of quality characteristics for IoT applications which specifically emphasizes the aspects of security, privacy, reliability and usability.

However, we did not find out a work that summarizes how the evaluation of NFRs for IoT applications has been conducted. Thus, in order to contribute with the NFR evaluation field, this work aims to provide a comprehensive view on approaches, methods, tools, and processes used for the evaluation of NFRs for IoT applications as well as the main challenges faced by the evaluators.

For this, we apply the systematic mapping methodology, which is designed to give an overview of a research topic by classifying and counting contributions in relation to the categories of that classification (Petersen et al., 2015).

The remainder of this paper is organized as follows: Section 2 provides a theoretical background, discussing IoT challenges, and the non-functional requirements. Section 3 describes our methodology; Section 4 presents the results; in Section 5, we discuss the results; and in Section 6 we expose our final considerations and future work.

2 BACKGROUND

This study aims to provide an overview of how NFRs' assessments have been conducted for the IoT applications. Therefore, we consider it appropriate to provide a theoretical foundation regarding the IoT and NFRs as follows.

2.1 Internet of Things

The term Internet of Things was introduced by Kevin Ashton in 1999 and was associated with RFID technology (Ashton, 2009).

Since then, the purpose and use of this technology have evolved, and today IoT can be defined as a paradigm where smart objects interact in an environment through a wireless connection, being able to cooperate in providing services and achieving common goals (Atzori et al., 2010).

IoT can be considered an extension of Ubiquitous Computing (Carvalho et al., 2020), which refers to devices connected everywhere in such a transparent way that we will not realize they are there (Weiser, 1991).

Due to their similarities, such as mobility and context-awareness, the artifacts that come from Ubiquitous Computing are suitable for IoT applications (Andrade et al., 2017). Therefore, in this work, we consider the NRFs focused on Ubiquitous Computing as suitable for IoT applications.

On the other hand, IoT applications have also some singularities, such as interconnectivity, heterogeneity, and services related to objects.

We present then the following list of IoT features and their definitions (Patel et al., 2016):

- **Interconnectivity:** In IoT applications, different objects can be connected, sharing information within a communication infrastructure.
- **Object-related Services:** IoT applications can provide services related to the objects that integrate the solution, such as privacy protection and semantic consistency between objects.
- **Heterogeneity:** An IoT application is composed of heterogeneous devices, both in aspects related to hardware and aspects related to how they were implemented. However, these devices can interact with other devices or service platforms through different networks.
- **Dynamicity:** The state of devices and the context changes dynamically. Devices can, for example, be connected or disconnected, vary in location, have their settings changed, among others. The number of devices that makes up an IoT application can also vary dynamically, depending on the environment and other entities' presence (for example, objects and people).
- **Scalability:** IoT applications provide the recognition of each object that makes up a solution and ensure communication between them. Since the number of objects that makes up an IoT solution can vary, the system must remain operational regardless of the number of connected objects.
- **Security:** IoT applications must be designed with the security of their use in mind; this includes personal data and their user's well-being.
- **Interconnectivity:** Allows network access and devices' ability to consume and produce data within an IoT solution.

Limitations related to these features diminish their potential and impact usability (Rowland et al., 2015). Therefore, it is critical to ensure that these properties are performing as expected in IoT applications.

2.2 Non-Functional Requirements

Non-Functional Requirements (NFRs) can be defined as requirements that are not directly related with specific functionalities offered by the software. They can be related to the emerging properties of the system, such as Reliability and Security (Sommerville, 2011).

According to (Wiegers and Beatty, 2013), quality characteristics are also known as a type of NFRs and they describe the product's characteristics in various dimensions considered important by the stakeholders, such as security and usability.

Thus, the software quality assurance demands that quality characteristics (or NFRs) are specified, measured, and evaluated, whenever possible, using validated or widely accepted measures and measurement methods (ISO/IEC 25000, 2011).

Another important point to stress in this paper concerning the evaluation of NFRs is that they can be correlated, which means that one NFRs can has a impact in another one. This impact could be positive (helps) or negative (hurts) (Wiegers and Beatty, 2013).

3 METHODOLOGY

As we mentioned in the introduction section, this research aims to identify tools, methods, approaches, and processes for evaluating NFRs in IoT applications.

To this end, we conducted a systematic mapping of the literature (SML), following the guidelines proposed by (Kitchenham and Charters, 2007), which divides the research conduction into three stages: Planning (Section 3.1), Conduction (Section 3.2), and Analysis and Reporting (Section 4).

3.1 Planning

In the first stage of the SML methodology, we set up all the research parameters for conducting the research in a document called the research protocol. In this protocol, we defined the research questions, the search strategy, the selection criteria, and the data to be extracted.

3.1.1 Research Questions

According to the aim of this study, the following research question was defined:
RQ1 - How Are the Non-Functional Requirements Evaluations Conducted in IoT Applications?

To better answer this question, we had also defined a set of secondary questions as follows:

- SQ1 - Which are the approaches, tools, methods, and processes used to evaluate non-functional requirements in IoT applications?
- SQ2 - Which are the non-functional requirements observed when evaluating IoT applications??
- SQ3 - Which are the challenges faced when evaluating non-functional requirements?

3.1.2 Search Strategy

The first step in selecting the papers that answered our search questions was to conduct an automated database search.

For this, we used PICO (Population, Intervention, Comparison, and Outcomes), which is a strategy suggested by Kitchenham and Charters (2007) to identify keywords related to the defined search questions for the search string.

- **Population:** In software engineering, the population can represent a specific software engineering function, an application area, or an industry group. In our context, the population was defined as IoT applications, and we also considered ubiquitous and pervasive systems due to their similarities;
- **Intervention:** Intervention is defined with the methodology, tool, technology, or software procedure used to address a specific issue. In our case, the intervention was defined as the non-functional requirements;
- **Comparison:** Comparison can be defined as the methodology, tool, technology, or procedure with which the intervention is being compared. For this research, we do not define elements of comparison;
- **Outcome:** Outcomes should relate to factors of importance to practitioners in the study area. In our case, we selected terms that represented evaluation approaches as outcomes.

For each PICO element, we also selected synonyms to minimize the risk of restricting the search results. Table 1 shows the terms chosen by each category.

Table 1: Selecting search terms.

PICO Strategy	
Population	("Internet of Things" OR IoT OR "Pervasive*" OR "Ubiquitous")
Intervention	"non-functional requirement" OR nfr OR "non-functional property" OR "quality characteristic" OR "quality attribute" OR "quality requirement" OR "extra-functional requirement" OR "non-behavioural requirement" OR "quality factor")
Comparison	No terms selected
Outcome	(evaluation OR assessment OR verification OR validation) AND (method OR tool OR technique OR approach OR process)

When connecting the search terms with logical operators, we elaborated the following search string:

> ("Internet of Things" OR IoT OR "pervasive" OR " ubiquitous") AND ("non-functional requirement*" OR nfr OR "non-functional propert*" OR "quality characteristi*" OR "quality attribute*" OR "quality requirement*" OR "extra-functional requirement*" OR "non-behavioural requirement*" OR "non-behavioral requirement*" OR "quality factor*") AND (evaluation OR assessment OR verification OR validation) AND (method* OR tool* OR technique* OR approach* OR process*)

3.1.3 Research Sources Selection

We applied the search string in two databases that were chosen due to their good coverage and stability: Scopus[1] and Web of Science[2]. Therefore, Scopus incorporates other important bases for the Software Engineering field, such as ACM and IEEE.

In addition, we also performed a snowballing forward procedure, which means identifying new papers based on a set of papers that cite the paper being examined (Wohlin, 2014).

3.1.4 Study Selection Criteria

We selected for this research, papers that present tools, approaches, methods, or processes for evaluating non-functional requirements for IoT applications.

As for time range, once IoT was first cited in 1999 (Ashton, 2009), articles published between 2000 and 2019 were included in the current research. To ensure the correct interpretation of our research results and the replicability of the study, we limited our search to papers written in English.

Regarding the exclusion criteria, we did not consider eligible for this research papers that:

- are secondary or tertiary works;
- are books, technical reports, white papers, short papers (less than 5 pages);
- are not available for download; and
- do not present tools, approaches, methods, or processes of non-functional requirements evaluation for IoT applications.

3.1.5 Data Extraction

After we select the studies, they were submitted to the data extraction step that consists of exploring the work selected to extract information that will help us to answer our research questions.

Table 2 presents the data to be extracted in the selected papers.

3.2 Conducting

This conducting stage was divided into two steps. First, we applied the search string in the Web of Science and Scopus databases. We selected the papers through the study selection criteria. At the end of this process, we obtained a set of approved papers. Then, we used the selected papers to apply the snowballing forward procedure (Wohlin, 2014).

3.2.1 Fist Step: Search on Databases Sources

We started by applying the string search to the selected databases.

The search string returned 174 papers, 121 by Scopus and 51 by Web of Science. After removing 49 duplicated studies, we obtained 125 papers for the title/abstract screening. At this step, we excluded 88 papers based on our study selection criteria. Thus, we got a set of 37 papers eligible for the entire reading.

[1]http://www.scopus.com/search
[2]http://www.webofknowledge.com

Table 2: List of data to be extracted.

Data extraction form	
Study metadata	Title, authors, and year of publication.
Approaches, methods, tools, or process	Strategy adopted to evaluate the NFRS.
Type of system	Ubiquitous System or IoT application.
NFRs	The NFRs evaluated.
Evaluation focus	System in development, system implemented or both.
Challenges	The challenges on evaluating NFRs reported within the paper.

After downloading and reading the full text of the 37 papers, we excluded 27 papers that had not answered our research questions. Thus, we got a set of 10 papers for data extraction.

3.2.2 Second Step: Snowballing Forward

To complement the search results through the databases, we decided to perform the Forward Snowballing procedure, which consists of choosing key papers from the study area and analyzing the papers that have cited them (Wohlin, 2014).

For this research, we analyzed the citations referring to the 10 papers selected during the first phase. We performed these search through Google Scholar [3], by searching for each key papers, and then for all the papers that cited them.

Thus, 80 papers were identified and submitted to the same steps and study selection criteria used in the first stage. At the end, we excluded 78 papers that did not answer our research questions and selected 2 papers for data extraction.

4 RESULTS

This section describes the third step of our SML (*i.e.*, Analysis and Reporting), where we analyzed and summarized the research results to answer the research question: *RQ1 - How are the non-functional requirements evaluations conducted in IoT applications?*

Since we highlight the singularities of IoT applications, it is necessary to understand how these solutions have been evaluated.

Finally, we selected 12 documents for data extraction, following the data extraction form. After that, we analyzed the results and answered our research questions. Table 3 shows the final set of studies and their respective ID.

Table 3: List of final set of studies.

ID	Reference
S1	(Ruiz-López et al., 2012)
S2	(Ruiz-López et al., 2013)
S3	(Kim et al., 2017)
S4	(Rocha et al., 2017)
S5	(Munnelly and Clarke, 2008)
S6	(Jazdi et al., 2016)
S7	(Ruiz-López et al., 2013)
S8	(Badii et al., 2018)
S9	(Ghasemi et al., 2019)
S10	(Chauhan and Babar, 2017)
S11	(Filho et al., 2020)
S12	(Alegre-Ibarra et al., 2018)

Figure 1 represents the PRISMA Flow Diagram (Moher et al., 2009) that describes the process adopted to conduct this research and its results.

Figure 2 and Figure 3 show, respectively, the distributions of studies by the type of systems that they were focused on and the type of NFR evaluation, if they were focused on systems in development or systems already implemented.

SQ1 - Which Are the Approaches, Tools, Methods, and Processes Used to Evaluate Non-Functional Requirements in IoT Applications?

We identified 2 tools, 6 approaches, 1 method, and 1 process that can be used for the evaluation of NFRs. Table 4 presents the strategies identified for evaluating NFRs in IoT systems.

SQ2 - Which Are the Non-Functional Requirements Observed When Evaluating IoT Applications?

Once we understood what had been used to conduct the evaluations, it is important to identify if the eval-

[3] http://scholar.google.com

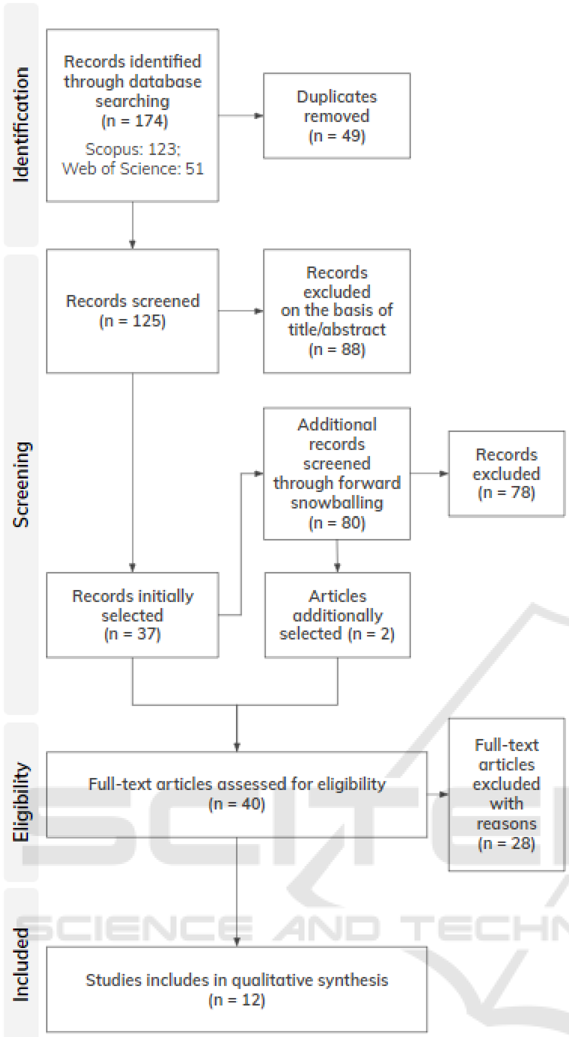

Figure 1: PRISMA flow diagram.

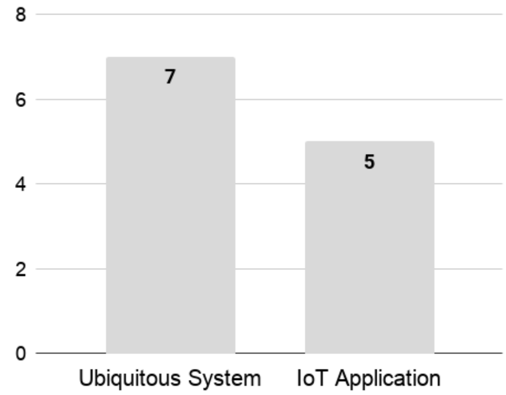

Figure 2: Type of system prioritized by the studies.

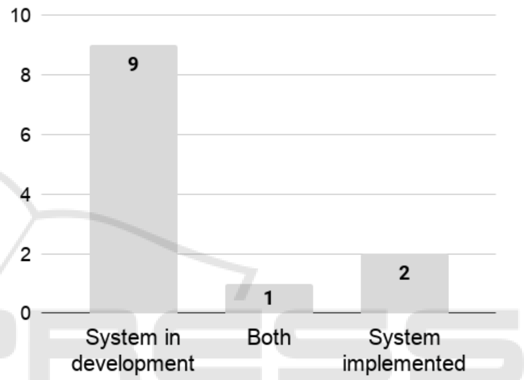

Figure 3: Focus of NFR Evaluation prioritized by the studies.

uators had considered specific NFRs to evaluate IoT applications.

We found 7 studies that described one or more NFRs as suitable for evaluating ubiquitous systems or IoT applications.

A total of 42 NFRs were identified [4]. Table 5 shows the list of NFRs considered during quality evaluations in IoT applications.

SQ3- Which Are the Challenges Faced When Evaluating Non-Functional Requirements?

By analyzing the final set of studies, we also identified some challenges concerning the evaluation of NFRs in IoT applications.

The most recurrent challenge is the necessity to deal with context-awareness. Other problems are the lack of a systematic approach and appropriate methods for evaluating non-functional requirements in IoT applications.

[4]The list of 42 NFR with its descriptions is available on https://github.com/great-ufc/NFRs4IoT

5 DISCUSSION

We performed a systematic mapping to answer the following primary research question: How are the non-functional requirements evaluations conducted in IoT applications?

Moreover, to better address the aspects involved in this question, we decided to divide this macro question into three secondary questions (SQs). The answers came from a detailed analysis of 12 out of 174 papers returned from the search in databases and the snowballing forward application.

Regarding SQ1, we noticed that most of the approaches, methods, and tools are focused on the requirements elicitation stage and not on evaluating if the IoT systems meet the NFRs previously established.

Table 4: Strategies identified by each study.

Study	Proposal	Type
S1	MD-UBI	Process
S2	MD-UBI	Process
S3	Architecture-based energy evaluation	Approach
S4	HUbis	Tool
S5	GQM	Method
S6	Determination of the software reliability approach	Approach
S7	REUBI	Method
S8	Performance evaluation	Approach
S9	ATAM scenario-based approach	Approach
S10	Reference Architectures for Design and Evaluation of Web of Things Systems	Approach
S11	MALTU	Approach
S12	RC-ASEF	Tool

Also, we only identified one process by this research, MD-UBI (Ruiz-López et al., 2013). This process was defined to support developers and evaluators in elicitation, representation, and evaluation of requirements, focusing on NFRs. This process is model oriented and aims to develop high-quality Ubiquitous Systems, covering the entire software development lifecycle.

Regarding to SQ2, we identified 42 non-functional requirements.

Among the 42 NFRs identified, 14 of these are present as characteristics and sub-characteristics in the quality models proposed by ISO/IEC 25000 (2011).

- System/software product quality: adaptation, availability, ease of use, interoperability, maintenability, modifiability, performance, reliability, reusability, security, testability and usability.
- Quality in use: efficiency and effectiveness.

Two of the selected papers have also cited 27 quality characteristics for ubiquitous systems. This set is proposed by Carvalho et al. (2017) and has some characteristics in common with the two quality models proposed by ISO/IEC 25000 (2011), but it contains specific characteristics for ubiquitous systems:

Table 5: NFRs distribution per study.

NFRs	Cited by
Acceptability	S4, S11
Adaptation	S4, S11
Attention	S4, S11
Availability	S4,S9, S10, S11
Calmness	S4, S11
Context-awareness	S4,S11
Comprehensibility	S5
Data Input	S4,S11
Device Capability	S4, S11
Ease of use	S4,S11
Effectiveness	S4, S11
Efficiency	S4,S11
Elasticity	S10
Energy efficiency	S3
Familiarity	S4,S11
Flexibility	S4,S11
Information display	S4, S11
Interconnectivity	S4, S11
Interoperability	S9, S10
Maintenability	S5
Maneageability	S5
Mobility	S4, S11
Modifiability	S9
Multi-tenancy	S10
Network Capability	S4,S11
Performance	S8, S9
Positioning of components	S4,S11
Predictability	S4, S11
Privacy	S4,S11
Reliability	S4,S6, S10, S11
Reusability	S5
Robustness	S4,S11
Safety	S4,S11
Scalability	S4,S5, S8, S10, S11
Security	S4,S9, S10, S11
Simplicity	S4,S11
Testability	S5
Transparency	S4,S11
Trust	S4, S11
Usability	S4,S5, S9, S11
User Satisfaction	S4,S11
Utility	S4,S11

- Acceptability, attention, calmness, context-awareness, device capability, familiarity, interconnectivity, mobility, network capability, predictability, privacy, robustness, safety, scalability, simplicity, transparency, trust, user satisfaction, and utility.

Given the similarities between IoT applications and ubiquitous systems, the use of this set of quality characteristics is also applicable for conducting quality evaluations on IoT systems.

The most evaluated NFR was Scalability, which is the ability to provide services to a few or a large number of users (Carvalho et al., 2017). Scalability was considered an important NFR to evaluate by 41,6% of the studies (5 papers). Another NFR identified is related with scalability:

- Elasticity: The ability of the system to provide particular service on demand during a time interval (Chauhan and Babar, 2017).

Availability, reliability, security and usability were also highlighted. They were both cited by 33% of the studies (4 papers).

For SQ3, we identified that the most significant challenge when evaluating IoT systems is the context-awareness, which is the system's ability to discover and take advantage of contextual information such as user location, time of day, and user activity (Musumba and Nyongesa, 2013). Thus, it is necessary to ensure that the system correctly identifies the contextual information, so the users will be benefited instead of affected by this non-functional requirement.

Another challenge is the lack of specific approaches for the evaluation of NFRs in IoT applications. This result is in line with the discussion held at SQ1, where we identified only 3 studies that focused on the evaluation of NFRs satisfaction and only one process that has a step to evaluate NFRs in the final product.

6 CONCLUSION

IoT applications are gaining more and more space in our daily lives. Therefore, it is necessary to look at how these solutions have been evaluated, mainly concerning non-functional requirements, because they are directly related to the software quality evaluation and the user expectations through the system.

In this work, we perform a systematic mapping on the evaluation of non-functional requirements in IoT systems to provide a comprehensive view about this field.

As the main contributions, we identify artifacts (tools, methods, approaches, and processes) to evaluate NFRs and we perceived the lack of artifacts and systematic approaches to evaluate whether IoT applications satisfy the previously established non-functional requirements or not.

We also identified 42 NFRs that can be considered to design and evaluate of IoT applications. Most existing artifacts are focused on the usability and reliability of the solutions, which may represent a concern about how the users interact and how they relate to IoT applications.

As future work, there is a need to develop and validate a process to systematize the NFR evaluation steps for IoT applications with a particular eye to the human-thing and thing-thing interactions.

ACKNOWLEDGEMENTS

We would like to thank CNPq for the Productivity Scholarship of Rossana M. C. Andrade DT-2 (N°315543 / 2018-3) and UFC, FASTEF, and Dell cooperation using the Brazilian Informatics Law (No 10.176of 1/11/2001) incentives that help us to support our research laboratory.

REFERENCES

Alegre-Ibarra, U., Augusto, J. C., and Evans, C. (2018). Rc-asef: An open-source tool-supported requirements elicitation framework for context-aware systems development. In *2018 Federated Conference on Computer Science and Information Systems (FedCSIS)*, pages 829–838.

Andrade, R. M., Carvalho, R. M., de Araújo, I. L., Oliveira, K. M., and Maia, M. E. (2017). What changes from ubiquitous computing to internet of things in interaction evaluation? In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, volume 10291 LNCS, pages 3–21. Springer Verlag.

Ashton, K. J. (2009). That 'internet of things' thing.

Atzori, L., Iera, A., and Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15):2787–2805.

Badii, C., Belay, E. G., Bellini, P., d. Cenni, Marazzini, M., Mesiti, M., Nesi, P., Pantaleo, G., Paolucci, M., Valtolina, S., Soderi, M., and Zaza, I. (2018). Snap4city: A scalable iot/ioe platform for developing smart city applications. In *2018 IEEE SmartWorld, Ubiquitous Intelligence Computing, Advanced Trusted Computing, Scalable Computing Communications, Cloud Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/ SCALCOM/ UIC/ ATC/ CBDCom/ IOP/ SCI)*, pages 2109–2116.

Bures, M., Bellekens, X., Frajtak, K., and Ahmed, B. S. (2020). A comprehensive view on quality characteristics of the iot solutions. In José, R., Van Laerhoven, K., and Rodrigues, H., editors, *3rd EAI International Conference on IoT in Urban Space*, pages 59–69, Cham. Springer International Publishing.

Carvalho, R. M., Andrade, R. M., and Oliveira, K. M. (2020). How developers believe invisibility impacts nfrs related to user interaction. In *2020 IEEE 28th International Requirements Engineering Conference (RE)*, pages 102–112. IEEE.

Carvalho, R. M., Castro Andrade, R. M., Oliveira, K. M., Sousa Santos, I., and Bezerra, C. I. (2017). Quality characteristics and measures for human—computer interaction evaluation in ubiquitous systems. *Software Quality Journal*, 25(3):743–795.

Chauhan, M. A. and Babar, M. A. (2017). Chapter 7 - using reference architectures for design and evaluation of web of things systems**this chapter describes a method for software architecture design, analysis, evaluation and evolution of individual internet of things (iot) subsystems and how individual iot subsystems can be used for design of web of things (wot) systems.: A case of smart homes domain. In Sheng, Q. Z., Qin, Y., Yao, L., and Benatallah, B., editors, *Managing the Web of Things*, pages 205 – 228. Morgan Kaufmann, Boston.

Chung, L. and Prado Leite, J. C. (2009). *On Non-Functional Requirements in Software Engineering*, page 363–379. Springer-Verlag, Berlin, Heidelberg.

Filho, J. C. S., Brito, M. R. F., and Sampaio, A. L. (2020). Comparing heuristic evaluation and maltu model in interaction evaluation of ubiquitous systems. In *Anais Estendidos do XIX Simpósio Brasileiro sobre Fatores Humanos em Sistemas Computacionais (IHC'20)*, Porto Alegre, RS, Brasil. SBC.

Ghasemi, F., Rezaee, A., and Rahmani, A. M. (2019). Structural and behavioral reference model for IoT-based elderly health-care systems in smart home. *International Journal of Communication Systems*, 32(12):e4002.

ISO/IEC 25000 (2011). Iso/iec 25000 - systems and software engineering - systems and software quality requirements and evaluation (square). Technical report.

Jazdi, N., Oppenlaender, N., and Weyrich, M. (2016). Quantification of the quality characteristics for the calculation of software reliability. *IFAC-PapersOnLine*, 49(30):1 – 5. 4th IFAC Symposium on Telematics Applications TA 2016.

Kim, D., Choi, J.-Y., and Hong, J.-E. (2017). Evaluating energy efficiency of internet of things software architecture based on reusable software components. *International Journal of Distributed Sensor Networks*, 13(1):1550147716682738.

Kim, M. (2016). A quality model for evaluating IoT applications. *International Journal of Computer and Electrical Engineering*, 8(1):66–76.

Kitchenham, B. and Charters, S. (2007). Guidelines for performing systematic literature reviews in software engineering. Technical Report EBSE 2007-001, Keele University and Durham University Joint Report.

Moher, D., Liberati, A., Tetzlaff, J., and Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the prisma statement. *Annals of Internal Medicine*, 151(4):264–269.

Munnelly, J. and Clarke, S. (2008). Infrastructure for ubiquitous computing: Improving quality with modularisation. In *Proceedings of the 2008 AOSD Workshop on Aspects, Components, and Patterns for Infrastructure Software*, ACP4IS '08, New York, NY, USA. Association for Computing Machinery.

Musumba, G. and Nyongesa, H. (2013). Context awareness in mobile computing: A review. *International Journal of Machine Learning and Applications*, 2(1):5.

Patel, K. K., Patel, S. M., and Scholar, P. G. (2016). Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*.

Petersen, K., Vakkalanka, S., and Kuzniarz, L. (2015). Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology*, 64:1 – 18.

Rocha, L. C., Andrade, R. M. C., Sampaio, A. L., and Lelli, V. (2017). Heuristics to evaluate the usability of ubiquitous systems. In Streitz, N. and Markopoulos, P., editors, *Distributed, Ambient and Pervasive Interactions*, pages 120–141, Cham. Springer International Publishing.

Rowland, C., Goodman, E., Charlier, M., Light, A., and Lui, A. (2015). *Designing connected products: UX for the consumer Internet of Things*. " O'Reilly Media, Inc.".

Ruiz-López, T., Noguera, M., Rodríguez Fórtiz, M. J., and Garrido, J. L. (2013). Requirements systematization through pattern application in ubiquitous systems. In van Berlo, A., Hallenborg, K., Rodríguez, J. M. C., Tapia, D. I., and Novais, P., editors, *Ambient Intelligence - Software and Applications*, pages 17–24, Heidelberg. Springer International Publishing.

Ruiz-López, T., Rodríguez-Domínguez, C., Noguera, M., and Rodríguez, M. J. (2012). A model-driven approach to requirements engineering in ubiquitous systems. In Novais, P., Hallenborg, K., Tapia, D. I., and Rodríguez, J. M. C., editors, *Ambient Intelligence - Software and Applications*, pages 85–92, Berlin, Heidelberg. Springer Berlin Heidelberg.

Ruiz-López, T., Rodríguez-Domínguez, C., Noguera, M., Rodríguez, M. J., Benghazi, K., and Garrido, J. L. (2013). Applying model-driven engineering to a method for systematic treatment of nfrs in ami systems. *J. Ambient Intell. Smart Environ.*, 5(3):287–310.

Sommerville, I. (2011). Software engineering 9th edition. *ISBN-10*, 137035152:18.

Uckelmann, D., Harrison, M., and Michahelles, F. (2011). *An Architectural Approach Towards the Future Internet of Things*, pages 1–24. Springer Berlin Heidelberg, Berlin, Heidelberg.

Weiser, M. (1991). The computer for the 21 st century. *Scientific american*, 265(3):94–105.

Wiegers, K. and Beatty, J. (2013). *Software Requirements, Third Edition*. Microsoft Press.

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*, EASE '14, New York, NY, USA. Association for Computing Machinery.