Testing Strategies for Smart Cities applications: A Systematic Mapping Study

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ABSTRACT

Context: Smart Cities are urban areas that enable the development of applications to improve city resources management, through the use of information technology such as Internet of Things and cloud computing, as well as government data availability and citizen participation. Some challenges identified in the development of solutions for this context are: scalability, modularity and security. **Goal:** Testing activities are critical to the verification and validation of Smart City solutions, so our goal is to develop a map of test strategies for applications developed in the context of Smart Cities. **Method:** For this study we defined a systematic literature review protocol to identify, select, analyze and synthesize the results of previously published empirical studies in the software engineering literature, related to testing Smart Cities applications. **Results:** In this systematic mapping, 13 articles were selected, that have identified test strategies used by developers for the application testing process. We have also identified some difficulties faced in the process of testing these applications through reports present in the works selected in this mapping. **Conclusion:** Our research synthesized evidence that we hope might serve as a data source for academic research and industrial practice. As future work we plan to apply our results highlighting a case study in real applications to validate the collected evidence.

CCS CONCEPTS

• **Software and its engineering** → **Software testing and debugging**; *Empirical software validation*; • **General and reference** → *Empirical studies*;

KEYWORDS

Smart City, Tests, Mapping Study

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1 INTRODUCTION

Smart Cities are urban areas that enable the development of applications to achieve improvements in resource management of the city, through the use of information technology such as Internet of Things (IoT), cloud computing, government data availability and citizen participation. Smart Cities are an approach that has already been discussed for some time [12], which are imagined as capable of managing the use of their resources, providing improvements in citizens' quality of life, in different dimensions, such as mobility, governance, environment, economy, people and life [5]. Through recent technological advances and increasing access to such technology, the number of IoT devices already exceeds the amount of mobile devices that are used by people. IoT is then expected to consolidate as an essential part of Smart Cities [12].

Testing these large scale applications is usually hard, since they involve a large number of devices, sensors, and vast amounts of generated data. Moreover, what works well in one application may not work in another. As an example, in the context of solutions proposed for urban traffic management, some test beds already exist [11, 13, 16]. These may work fine, however we can not say that they will work well in all cities in which such solution is implemented. Currently, no standard has been found in the literature to be adopted or even a catalog of best practices in which the community can rely to define which test strategies fits best for a particular solution to be implemented.

Therefore, based on this lack of evidence, the motivation to carry out a study to propose a solution to this identified gap arises. We are interested in trying to identify the strategies used to test applications developed for the context of Smart Cities. To achieve this goal, we systematically examined the literature with the objective of identifying, analyzing and mapping the evidence about this issue, seeking to answer some questions directed to the strategies that are used by the developers to test. Moreover, we are also interested on trying to identify possible patterns of existing test strategies and potential difficulties to test Smart Cities applications. In the search process in the literature that was carried out, we found some studies that involve Smart Cities [4, 9, 14, 24]. However, these studies do not deal with testing strategies, which are the focus of our research.

By answering these questions based on the existing literature, we identified three main strategies that are commonly used to help developers in the application testing process for the context of Smart Cities. The most commonly reported strategy among those three is that of test-beds, which are platforms that attempt to be as close to reality as possible, to enable verifying and experimenting with applications [6]. We have also identified a number of challenges faced by developers that were reported in the selected studies. A recurring challenge is that proposed solutions are usually very

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narrow and limited to a specific context. Based on the results we obtained, we hope to provide relevant data that might be useful for the testing processes of Smart Cities applications. Moreover, we also pose some challenges and implications for future research and industrial practice.

The rest of this article is organized as follows. In Section 2, we present the basic concepts and related works. In Section 3, we present the systematic review method followed in this study. In Section 4, we present the results of our review and the answers to the research questions. In Section 5, we discuss the findings of our review. Finally, in Section 6, we present our conclusions and proposals for future work.

2 BACKGROUND AND RELATED WORK

This section presents existing definitions of Smart Cities. We then show some related work, not specifically in the area of mapping studies, but on studies related to developing and testing Smart City applications.

2.1 Definitions

After conducting an exploratory search in the literature, we identified several definitions for the concept of Smart Cities, where several characteristic aspects are informed, such as mobility, governance, participation of society, among others. However, the use of information technology is always included in author definitions, so in the following we present some of the definitions we found in the literature:

> They are those that make systematic use of information and communication technologies to promote efficiency in the planning, execution and maintenance of urban services and infrastructures, in the best interests of the actors who work in these cities. Harrison and Donnelly [15]

> An Smart City has a defined geographical demarcation, that information and communication technologies, logistics, energy production act to create benefits for citizens as quality of life, inclusion and participation and improvement in environmental quality, it is governed by a set of well-defined subjects, capable of declaring the rules and policies for municipal government and development. Dameri [10]

> They are those capable of efficiently and effectively connecting the physical infrastructures and information and communication technologies, converging organizational, normative, social and technological aspects in order to improve the conditions of sustainability and quality of life of the population. Moss Kanter and Litow [19]

> These are those that combine the facilities of information and communication technologies and Web 2.0 with the organizational, design and planning efforts to dematerialize and accelerate bureaucratic processes, helping to identify and implement innovative solutions for city complexity management. Toppeta [23]

From the examined literature, we found the definitions that were presented above. It is possible to observe that some common points are reported by the authors. For instance, we notice that in the definitions, the use of (1) information and communication technologies is very common, as well as that the authors report that the solutions proposed for a Smart City should consider (2) improving the quality of life for their citizens. It is also possible to identify the reports on the (3) governmental aspects that should enable improvements in city management, facilitating and accelerating existing processes, which might be too bureaucratic. We are aware that there are other definitions for Smart Cities, but in this work we use these three points as the baseline for our study.

2.2 Related Work

A well-known Smart City project is the SmartSantander [2], which was developed in the city of Santander, in Spain. In this project, several IoT sensors were deployed providing a large infrastructure for collecting relevant information through a test scenario, also known as a test-bed. Test scenario means a standardized laboratory environment that is used to test new applications [5].

The Santander test-bed consists of 10 case study implementations that have an environmental monitoring consisting of approximately 2000 IoT devices on public lighting poles that provide different data such as noise, temperature, lighting and presence sensors. Moreover, outdoor parking management using 400 parking sensors buried under the asphalt in the main parking lots of the city, the management has the objective of detecting vacant parking spots in the parking lots. An extension named environmental monitoring mobile, used sensors installed in 150 public vehicles with the objective of collecting data in several points of the city. The intensity of traffic was also monitored with 60 devices located at strategic points in the city entrances to measure the main aspects related to traffic. At some crossroads of the streets there are panels which inform the available parking spaces. Parks and garden irrigation was also monitored with 50 devices to collect data. Augmented reality was used in points of interest in the city, with RFID and QR code tags. Participative sensing was also considered, with users using mobile phones to send relevant data to the SmartSantander platform. They also experimented with transceivers, where researchers can conduct tests in their experiments, such as data mining techniques and routing protocols. Finally, there was also experimentation in the service level, which differs from the previous one, in the sense that data that are not available by the native experimentation can be offered to the researchers for the development of new services. The SmartSantander test scenario enables service delivery and experimentation simultaneously, however the project does not process or store the generated data, which poses a challenge for its use in other Smart City applications.

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The work of Dameri Dameri [10] investigated IoT applications. One point that was strongly emphasized in the study was the difficulty of maintaining scalability during the development process. They report that testing such applications in a controlled environment may not be enough to understand and evaluate applications. As a proposed solution, they propose a simulation platform to test and debug applications before the solution is deployed. The proposal focuses on testing for IoT applications with a large number of devices developed for urban environments. For the platform, the authors define three main advantages: the ability to simulate large-scale systems, maximize code reuse and finally the high generality of simulated nodes.

In the United Arab Emirates, there is a project called Masdar City [1], that is being built to be a reference in sustainability and technology. One of the objectives of this project is to test initiatives developed for the context of Smart Cities with particular emphasis on the use of renewable power sources. During the year of 2018, in partnership with a electric vehicles company, the city is being used as a living labs for autonomous driving initiative, further enhancing the portfolio of initiatives in the context of Smart Cities. The city is still in its development process, with a number of other projects likely to emerge in the context of Smart Cities, and the prediction for the overall conclusion of this project is estimated to be 2025.

The municipality of West Hollywood is a small city that is located in Southern California with about 35,000 inhabitants. The city operates a test-bed initiative, which is used to test applications developed in the context of Smart Cities, relying on five key areas: *sustainability, mobility, access to government data, resilience, and transparency.* The city also developed the "WeHo Smart City" strategic plan to help cities better integrate applications developed for Smart Cities and make cities smarter [3].

3 METHOD

The research developed in this work can be characterized as exploratory, considering that the exploratory research establishes methods, techniques and criteria and aims to provide relevant information about the research topic [7]. For the development of this research the adopted methodology was that of a systematic mapping of the literature. Petersen et al. [20] defines systematic mapping as a search method to construct a classification of a particular field of the area of interest searched. For the correct implementation of this methodology, the definition of objectives, the development of a protocol to be followed by the participants of the research and the selection, extraction and analysis of data relevant to research of primary studies that are of research related to the theme of the mapping.

In the methodology of systematic mapping studies, the research questions are broader and more general when compared to those found in Systematic Literature Reviews (SLRs) [17] [8].

3.1 Research Questions

According to the presented context of this research, the research problem identified and addressed in this work is related to the absence of information about which test strategies are used in applications developed in the context of Smart Cities. The research question that guides the conduction of the study is presented in the following:

RQ1 *- What are the strategies used to test applications developed for the context of Smart Cities?*

In order to help on answering this research question, we have devised the following specific questions presented as follows:

RQ1.1 *Is there any testing pattern adopted by developers to test applications developed for the context of Smart Cities?*

RQ1.2 *What are the difficulties identified by developers to test applications developed for the context of Smart Cities?*

3.2 Data Sources and Search Strategy

We followed the Budgen and Brereton [8] approach for using Boolean operators AND and OR to help construct search strings. Table 1 shows the engines used in the automatic search of the research. It is important to point out that the engines were selected based on their relevance to the research community and the availability to perform the downloads of the selected papers.

Table 1: Search Engines

Search Engine	Link
ACM Digital Library	https://dl.acm.org
IEEE Digital Library	https://ieeexplore.ieee.org
ScienceDirect	https://www.sciencedirect.com/
Scopus	https://www.scopus.com/
EI Compendex	https://www.engineeringvillage.com/
Springer Link	http://www.springer.com.br/

After several tests, we have defined a search string that is presented in the following. Some adjustments were necessary to get as many works as possible relevant to this scientific study. It is important to note that some syntax formatting adjustments have been applied to the string according to the search engine rules.

```
application AND ("Smart City" OR "Smart Cities") AND
test
```

3.3 Inclusion and Exclusion Criteria

From the initial set of 2,414 articles, we selected papers that present strategies, concepts, guidelines, discussions and lessons learned used to test applications developed for the context of Smart Cities. We excluded studies that failed to satisfy any of the seven Exclusion Criteria (CE) which are shown following:

EC01 *Written in any language but English.*

EC02 *Not accessible on the Web.*

EC03 *Invited papers, keynote speeches, workshop reports, books, theses, and dissertation.*

EC04 *Incomplete documents, drafts, slide of presentations, and extended abstracts.*

EC05 *Addressing other areas besides computer science.*

EC06 *Papers that do not present any type of findings or discussions about strategies used to test applications developed for the context of Smart Cities.*

EC07 *Non-accessible studies.*

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3.4 Study Selection

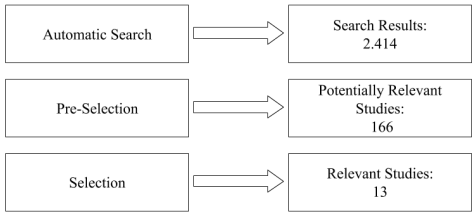
The selection stage of the primary studies was carried out by two researchers, working independently. In this stage, we selected the studies by reading the title, abstract and keywords. Table 2 presents the results of the automatic search performed in this mapping.

Table 2: Search Engines and their corresponding results in number of papers

Engine	Papers
ACM Digital Library	159
IEEE Digital Library	330
ScienceDirect	883
Scopus	121
EI Compendex	276
Springer Link	645
	2414

In this stage, 166 articles were selected to continue in the mapping selection stage. After we carried out the selection phase of the studies, each researcher applied the exclusion criterion (EC06) to keep only those articles that contain relevant information to answer at least one of the research questions. At this stage, articles dealing with different themes from the research carried out in this study were excluded. Duplicated results were also deleted. When it was identified that a study was published in more than one event (conference or journal), a review was undertaken in the publications for data extraction purposes. We conclude the selection stage with 13 articles. To resolve the disagreements and conflicts between the two researchers during the selection stage, consensus meetings were held. Figure 1 illustrates the selection stage of the articles.

Figure 1: Search Strategy - Study Selection



3.5 Data Extraction

After the final selection, the researchers, working independently, began the process of extracting relevant data from each selected article. They analyzed each article to fill out the form information, as described following in Table 3.

During the data extraction process, meetings were held to clarify conflicts and disagreements between researchers, aiming to improve the accuracy of the process, and therefore the reliability of extracted data.

Table 3: Data Extraction Form

Data	Description
Title	Title of the paper.
Year	Year of publication of the paper.
Study Goal	Main objective of the research analysed.
Study Motivation	Motivations for test applications.
Test	Strategies, concepts, guidelines, discussions, lessons learned used to test applications.
Evidence	Evidence of use of test.

3.6 Data Synthesis

To synthesize the obtained data, we performed the following steps:

Identify test strategies: For each article that was selected in the mapping, we aimed to identify reports of use of testing strategies that were described by the author.

Identify Evidence of Test Usage: Based on the reports of test usage in selected papers, we tried to identify evidence of implementation and testing.

Grouping the test strategies: After obtaining the information described above, we grouped the test strategies used by the works in applications developed for the context of Smart Cities.

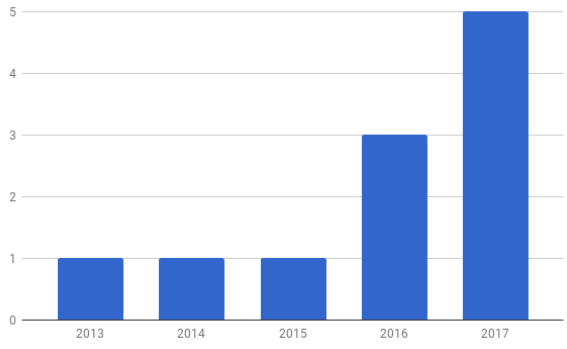
4 RESULTS

4.1 Mapping Study Overview

In this systematic mapping study, we analyzed 13 primary articles, with no publication period limit. The selection process occurred between September of 2017 and March of 2018. Table 4 summarizes the analyzed papers in chronological publication order.

A temporal distribution of the selected papers for this review is presented in Figure 2, where we can observe a slight increase in the number of studies during the temporal evolution. We can also observe that 41.67% of the selected studies (TS9, TS2, TS7, TS2 and TS1) are recent, published in 2017.

Figure 2: Temporal distribution of primary studies



4.2 Test Strategies

In this section we present the collected evidence about the use of test strategies in applications developed in the context of smart

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Table 4: Summary of Selected Papers

Title	Year	Ref.	Source
Streaming the Sound of Smart Cities: Experimentations on the SmartSantander test-bed	2013	TS10	Conference
SmarSantander: IOT experimentation over a smart city testbed	2014	TS11	Conference
TRESCIMO: European Union and South African Smart City Contextual Dimensions	2015	TS4	Conference
A Testbed for SCADA Cyber Security and Intrusion Detection	2015	TS12	Conference
Test of New Control Strategies for Room Temperature Control Systems Detection	2015	TS13	Conference
Designing a smart city playground: real-time air quality measurements and visualization in the City of Things testbed	2016	TS3	Conference
A Framework for IoT Service Experiment Plataforms in Smart-City Environments	2016	TS5	Conference
Living Labs for Smart Cities	2016	TS8	Conference
Lessons from SmartCampus: External Experimenting with User-Centric Internet-of-Things Testbed	2017	TS9	Conference
Living Lab Bamberg: an infrastructure to explore smart city research challenges in the wild	2017	TS2	Conference
Design of large scale network simulator using device emulator for Internet of Things	2017	TS7	Conference
IoTbed: A Generic Architecture for testbed as a Service for Internet of Things-Based Systems	2017	TS6	Conference
Poster Abstract: An Open Smart City IoT Test Bed	2017	TS1	Conference

cities following the research questions that were decided for this research.

RQ1 - What are the strategies used to test applications developed for the context of Smart Cities?

To answer this research question, we have analyzed all of the selected studies looking for evidence of the use of test strategies carried out by the authors. The results are summarized in Table 5.

Table 5: Test Strategies and their corresponding evidence sources

Test Strategies	Evidence
Test-bed	TS10 - TS11 - TS9 - TS6 TS4 - TS3 - TS12 - TS8 TS1 - TS13
Living Labs	TS2 - TS5 - TS8
Simulator	TS7 - TS12

After performing the analysis in the selected works, we managed to identify 3 common test strategies which are reported by the selected papers. These are strategies used to verify and validate solutions developed for the particular context of Smart Cities. It is likely that other testing strategies used in traditional software development projects, such as unit tests, may also be used on such projects.

We noticed that most articles report on the development and use of experimental testing infrastructure for conducting research and experiments of architectures, services and IoT applications in the context of some city. These are commonly known as Test-beds, which are platforms that make possible verifying and experimenting with projects using a near-to-reality environment [6].

A well-known test-bed is the one from the city of Santander, reported in the TS10 and TS11 articles. The authors of the TS13 study use the same strategy, but adopting a different terminology, namely that of Test-bench. They define a bench of tests to develop and carry out tests for controlling room temperature. From the test-bench it is possible to test the heating system of an apartment in a controllable environment under dynamic contour conditions.

From the reports on such articles, we have not identified a significant difference between test-bed and test-bench strategies. We believe that it is only a matter of terminology between the two terms and that the two strategies are equivalent.

According to Schumacher et al. Schumacher et al. [21], since 2003 the Living Labs concept has been used as a strategy for combining the government, academia and industry to develop solutions in certain areas of a city. In TS8, the main focus of the Living Lab for Smart Cities at the University of Guadalajara was to generate metrics that can be used to evaluate the performance of a city based on the current infrastructure and propose innovative solutions using Information Technologies.

The main objective of the Living Lab presented by TS2 is to provide an open infrastructure for research in applications developed based on sensors, providing researchers with the possibility of developing, testing and evaluating the developed applications.

The main focus in the development of test-beds is the creation of verification and experimentation platforms with maximum approximation to reality. The strategy of Living Labs comes with the purpose of trying to connect the governmental aspects, the academy, and also the industry. It also considers the development of platforms to test the proposed solutions to the context of Smart Cities.

The TS7 article proposes using the strategy of a simulator architecture to test and debug IoT application algorithms before they are deployed in the real environment. The focus of the simulator

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is on emulating a large scale system and proposed networking environments to perform interaction tests that occur within the IoT application.

The TS12 work reports on the catastrophic impacts that can occur in the case of attacks on intelligent traffic infrastructures. It also states how it is often unfeasible to enhance attack tests and mitigation strategies in real networks. The proposed solution is a simulated test-bed that simulates a traffic generator to perform network attack testing by providing system intrusion analysis. The authors report that this solution may help researchers to study the impact of different attack scenarios and to test new security solutions.

The strategy of using simulation to perform validation and experimentation in the proposed solutions is similar to the approaches of test-beds and living labs. Nonetheless, we understand that the main difference is related to the issue of creating environments close to reality. For instance, in the TS07 study, the authors report that the simulator is capable of providing infrastructure to easily test and debug application algorithms before they are deployed in a real environment. Therefore, such strategy might not be limited to a specific solution as we see in most of the test-beds seen in this mapping study. Another difference is related to the issue of scalability. Still on the TS07 study, authors claim that the architecture developed for the simulator focuses on large-scale systems, providing simulated environments for conducting interaction tests within the application. Therefore, it is important to take into account such differences when deciding which strategy to choose, based on the specific needs of the project. Through the needs and requirements of each solution, the developers can verify which strategy fits best avoiding possible problems in the verification and experimentation processes.

From what we identified in the articles selected in this systematic review, the identified strategies tend to prepare an environment of verification and experimentation that is as close to the reality as necessary for the solutions that are developed. However, we observed that it was not possible to identify a standard to be adopted for the development of test strategies for Smart City solutions.

RQ1.1 Is there any testing pattern adopted by developers to test applications developed for the context of Smart Cities?

After collecting evidence of testing for applications developed in the context of Smart Cities, we were able to identify the previously listed strategies. However, even though there is a commonality in terms of the used strategies, we could not detect or identify some kind of test pattern to be followed by the researchers or developers of such applications. This is mainly due to the fact that most of the test strategies are developed for some specific context which is not guaranteed to be reused in another application. Another relevant observation is that the financial investment in the majority of cases is confined to the project duration and does not aim at continuity after the project completion, causing a halt in the development of the test strategy, and potentially reducing the incentives for developing strategies that can later be reused in other contexts.

RQ1.2 What are the difficulties identified by developers to test applications developed for the context of Smart Cities?

During the process of analyzing the studies, we were able to identify some of the challenges and difficulties related to testing reported by authors in their research. Some of these are also related to the creation of test plans for applications developed for the Smart Cities context. Some of these reports are presented in the following:

> "...new technologies and solution-optimisations are constrained in terms of applicability to the context under which they have been tested..." - TS11

> "...there is a need for a test bed, which can enable exploration and experimentation..." - TS1

> "...Creating Internet-of-Things (IoT) solutions that can be deployed at scale requires adequate experimentation environments..." - TS9

> "...Experimenting on live systems is generally not advisable and impractical as this may deem the system unstable. Such situation calls for the need of an experimental setup equivalent or quite close to the real scenario for development and testing of security solutions...." - TS12

> "...The challenge for many smart-city test and experimentation platforms (TEPs), like living labs, has been the lack of sustainable value creation model..." - TS5

> "...Developing Smart Cities solutions faces the challenge of validating prototypes with respect to the following criteria: scalability, interoperability, modularity, resiliency, and security...." - TS8

Based on such reports, we can observe that testing such applications is still challenging. There is a recurrent need for testing and experimentation environments, and the inherent difficulty of testing such large-scale systems in terms of scalability, security, and other non-functional aspects also poses a challenge, since it is usually ill-advised to conduct tests on the actual systems while they are in production. In the following section we discuss potential implications for research and industrial practice related to our findings.

5 DISCUSSION

During the process of analyzing the articles we noticed that most of the works report on the need for devising test strategies and environments that support different applications developed in the context of Smart Cities. However, we also realize that there is no standard to be followed by developers because usually the test strategies which are used have been developed for a specific case and do not continue after the project completion.

5.1 Implications for Research

In this section, we discuss the implications of this mapping study for future software engineering research. From the results of this

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study we were able to identify some challenges faced by developers to test applications for the context of Smart Cities.

Based on the answers from RQ1.2, we observed that one of the main challenges for the developers is that the applications are developed for specific and narrow domains. Moreover, they are limited to the context where they have been tested, as TS2 reports. A considerable research challenge would be to attempt to develop testing patterns and strategies that are not limited to a specific solution but can be reusable in other solutions that are developed in the context of Smart Cities.

It is the case that, even though each application has its own set of specific features, in many cases there are recurring patterns related to these features, such as the use of localization technologies. Therefore, a direction towards this challenge would be to have at least a test-bed framework that could abstract away these common features, that could be then instantiated for each specific Smart City application.

Besides considering functional properties, we also have the challenge of limited context related to non-functional aspects of such applications, as well. For instance, the TS8 work reports on the difficulty of validating prototypes according to some criteria, such as scalability, interoperability, modularity, resilience, and security. In order to try to cover these criteria, it is necessary to have or develop strata of tests that meet these needs. In the TS9 study, it is reported that in order to create IoT solutions at scale, it is necessary to have environments of adequate experimentation for the developed solutions. From the knowledge that the five criteria mentioned above are difficulties faced to carry out the validation of prototypes of solutions, the need arises to develop scientific studies that can direct the developers to develop tests strategies that can cover such non-functional criteria.

The TS6 study raises a rather interesting question for future research: How can a resource-constrained IoT device researcher develop and test their IoT-based applications without making a significant investment in buying and maintaining a large number of IoT devices? We saw that another difficulty is the lack or continuity of resources for the developers, causing many experimental platforms to perish external funding ends, as the TS5 study reports.

In the research presented by TS9, some desirable properties for the test strategies are presented and can serve as motivation for new scientific researches. In the following, we present the needs:

- *Experimental environment realism.*
- *Heterogeneity of IoT devices.*
- *End User Involvement.*

Therefore, through the results presented in this study we hope to motivate researchers by means of these reports to carry out scientific research in this context providing data for the developers to use in their applications.

5.2 Implications for Industrial Practice

The implications for industrial practice that this study can offer are presented in two forms. First, the choice of a suitable testing strategy for the solution that was developed. Based on the common strategies reported on our results, developers already have an initial direction on decision making, in terms of how they can choose a particular test strategy to be adopted for the applications that have been developed in the Smart Cities context.

In the results section of this study we present the strategies reported by the works that were selected in the mapping. Based on these results, developers can save the time of searching the literature to try to find data that helps on choosing and establishing the testing process. This might also depend directly on the adopted culture for each company. For instance, if the company has the culture to seek information in the literature, our work might serve as a good data source for directing this search, and potentially helping to define the testing process that might be adopted in the company.

Second, our study might also be able to collaborate in the development of test strategies. One of our research questions is to try to identify the difficulties faced by the developers to test the applications developed in the context of Smart Cities. From our results related to this research question, when a certain company develops a test strategy, it can take into account the difficulties already reported by the developers that are listed in our results. This way, it can save time and reduce financial costs in the development process and also prevent itself from making possible failures that could happen if it did not have the previous knowledge of the difficulties already existent for these testing processes.

5.3 Validity and Limitations

For the accomplishment of this systematic review of the literature, we are based on the guidelines presented by Budgen and Brereton [8], in the study of threats to the validity of Teixeira et al. [22] and also the four main threats to validity presented by Wohlin et al. [25] which are: internal, external, construct and conclusion.

Internal validity: Skill levels in the development of systematic mapping of the literature can be considered a threat to the internal validity of the research. In trying to avoid this threat, several research planning meetings were held before starting the research. Another threat to the internal validity to be considered is the communication between the researchers. We tried to avoid that, by having researchers working independently in the selection, extraction and analysis stages, so that results were later merged, with possible divergences discussed. The number of researchers participating in this study is also a threat to be considered, since the participation of more researchers could offer a broader variety of opinions in consensus meetings in the selection, extraction and analysis stages of the study.

External validity: In order to mitigate the generalization of the results obtained in this study, we tried to avoid some threats. First, we considered the use of six search engines and also did not restrict the publication time of the studies to try to collect the maximum number of papers relevant to the search. Another threat is related to the search string used in the search engines. In trying to reduce this risk, we performed some refinements in the string. For instance, we performed some tests with the inclusion of more terms in the search string, such as the term "intelligent cities". However, the number of retrieved articles was not relevant in relation to the search string used in this study. Nonetheless, we believe that there may be a need for more refinements in the string to try to improve the obtained results.

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Construct validity: We can consider as a threat to construct validity the definition of our search strategy. In order to reduce the risk of this threat, we followed the steps reported by Kitchenham [18], searching for studies that were derived from our research question and also studying other systematic reviews already published in the literature.

Conclusion validity: For the results obtained in this study, a threat to conclusion validity is related to the fact that our results have not yet been applied in some possible scenario or Smart City application. Another issue is since there are no other mapping studies in this context that we are aware of, our results have not been confronted with other results from other studies.

6 CONCLUSIONS

Application testing activities are a very important step in the software development process. When ignored, the consequences might be costly and often lead to considerable problems such as rework in the application development process. Therefore, considering the fact that developing applications for the context of Smart Cities is still a recent development in industrial and research practice, in this study we performed a systematic review of the literature on the test strategies used in applications developed for the context of Smart Cities. We obtained in the automatic searches more than 2,000 primary studies and from these we selected 13 relevant studies to carry out our research.

From the results of our study, we present evidences of test strategies used in the applications, mainly test-beds, living labs, and simulators. We also identified through the reports of the selected works that there is no defined pattern of test strategies to be followed by the developers for the development of tests. Finally, we also presented the difficulties reported by the authors related to testing applications developed for the context of Smart Cities.

We discussed the possible implications of this research for future scientific research, proposing topics for researchers to conduct studies to deepen knowledge about testing strategies for Smart Cities applications. We also discussed the implications for the industrial practice reporting on the benefits our study could offer developers in the testing process for these applications. We hope that the results of this study will contribute to future research on this topic and that it may also benefit industry professionals in the application testing process.

From the results obtained in this study, some future work opportunities may be cited as a means of contributing to the improvement of research related to this context, such as: (1) conducting a case study from our results in real applications in the context of Smart Cities; (2) extending this systematic mapping of literature considering a broader search string and other search engines; and (3) evaluating our results through a replication of this research.

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