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An Empirical Study of Investigating Mobile Applications Development Challenges

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ABSTRACT Context: mobile application development is rapidly evolving with substantial economic and scientific interest. One of the primary reasons for mobile application development failure is the increasing number of mobile platforms; some organizations endorse mobile application development before understanding the associated development challenges of each target platform. Objective: the objective of this paper is to identify the challenges of native, web, and hybrid mobile applications, which can undermine the successful development of such applications. Method: we adopted a two-phase research approach: at first, the challenges were identified via a systematic literature review (SLR); and then, the identified challenges were validated through conducting interviews with practitioners. Results: through both research approaches, we identified nine challenges vital to the success of mobile application development and four additional challenges from interviews not reported in the literature. A comparison of the challenges (native, web, and hybrid) identified in SLR indicates that there are slightly more differences than similarities between the challenges. On the other hand, the challenges (native, web, and hybrid) identified in interviews indicates that there are more similarities than differences between the challenges. Our results show a weak negative correlation between the ranks obtained from the SLR and the interviews ($[rs(9) = -.034], p = 0.932$). The results obtained from our t-test (i.e., $t = 0.868, p = 0.402 > 0.05$) depicts that there is no significant difference between the findings of SLR and interviews. Conclusions: mobile application development organizations should try to address the identified challenges when developing mobile applications (native, web, or hybrid) to increase the probability of mobile application success.

INDEX TERMS Mobile application development, mobile apps development, mobile application software engineering, challenges and barriers, empirical study.

I. INTRODUCTION

Nowadays, mobile application development for smartphones has evolved tremendously due to ubiquity and popularity among end users. This rapid interest has drawn mobile application developers' attention over the last few years [1], [2]. Currently, millions of mobile applications are downloaded and used by users across the globe. There are different mobile applications stores (e.g., Google Play Store, the Apple App Store, and the Windows Phone Store) which offer free and paid mobile applications to users [3].

Mobile applications are mainly developed in three ways: native, web, and hybrid mobile applications. The native mobile application runs on the operating system of the device and thus needs to be adapted for various target devices. ''Native,'' enables developers to utilize full capabilities of a device, thus have better performance and is available for download via platform's dedicated application stores. However, developing a native application for multiple platforms requires expertise with the programming languages, Application Programming Interfaces (API) and Software Development Kits (SDKs) of each target platform, which demands additional resources (skills, time and costs) [1], [4].

The second method, mobile web application runs on the web servers and accessible via mobile web browsers and are highly portable across multiple mobile platforms. This method enables the application to be used across platforms which ultimately lessens development cost and time. Nevertheless, ''Mobile Web'' applications have no access to use device specific hardware features, i.e., camera or accelerometer. The third method, Hybrid mobile applications are resident

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on the devices as they are packaged within the browser control of the platform, i.e., 'native-wrapped' mobile web applications. These mobile apps can access the device hardware features and are available for download through the platform's application distribution store [1], [4].

With the rapid increase in number and diversity of mobile platforms, developing mobile applications has become very challenging for organizations since they need to develop the same applications across each target platform separately. The common practice in the industry is to follow native development approach for developing mobile applications but lack reuse of code for another platform; thus the same application must be re-implemented from scratch [5].

Like other software engineering domains, mobile application development has its own diverse set of new challenges which recently got attention to discuss with practitioners and researchers [6], [7]. Nevertheless, the majority of these research discussions are entirely anecdotal. While there are substantial qualitative studies [1]–[3] on different areas of mobile application development, to the best of our knowledge, no empirical study has been conducted to investigate quantitatively the challenges faced by real-world practitioners.

Our study aims to provide mobile application developers, with a comprehensive set of challenges which will support them in development of mobile applications (native, web and hybrid). Identifying these challenges will help industries to be ready for efficient mobile application development and facilitate the successful completion of mobile application development. To achieve this goal, we set the following research questions:

RQ1: What development challenges, as identified in the literature, are specifically related to native, web or hybrid mobile applications?

RQ2: What development challenges, as identified in real-world practice, are specifically related to native, web or hybrid mobile applications?

RQ3: What are the differences between the challenges identified in the literature and real-world practice?

RQ4: What challenges are specifically related to the 11 knowledge areas of SWEBOK?

Previously, we published at a conference the initial results of this work (RQ1) [8]. This paper is the extension in which we present the results from our empirical study on the mobile application development challenges in native, web or hybrid applications. Moreover, the interviews findings (real-world practice) are included in this paper (RQ2). Besides, we also compare the challenges identified through SLR and real-world practice (RQ3).

These research questions aim to address the problems associated with mobile application development (native, web or hybrid) failures, by providing organizations with the research capacity and knowledge needed to evaluate and improve their mobile application development readiness adequately. The remainder of this paper is organized as follows: Section II describes the motivation and related work. The research methodology is explained in Section III. In Section IV, we present the results of the SLR and the interviews study. The detailed summary of the results is provided in Section V. Section VI discusses the limitations of the study. Finally, Section VII provides the conclusion and discusses how the findings of our study can be further used by researchers in future research endeavors.

II. MOTIVATION AND RELATED WORK

The demands of mobile applications for smartphones and tablets have increased tremendously in the recent years [9]–[12]. To serve the demands of diverse users, mobile application developers follow some different development and distribution strategies, ranging from native, to the web, and hybrid applications. However, each of the strategies has their pros and cons. The most common problems reported in literature explicitly associated with native are fragmentation [13], testing [1], lack of reuse of code [7], and change management [7].

The challenges associated with the web are compatibility [13], user experience [14], and lack of access to device hardware features [13]. The challenges associated with hybrid mobile applications development are testing [15], user experience [5], and lack of tools support [16]. Organizations are facing the problem repeatedly to decide which strategy will serve and satisfy better the end users to meet their desired requirements efficiently. All these decisions are made based on the availability of resources (time and budget), skills/expertise and development tools.

Some research efforts analyzed and compared all these available development strategies. The work of Huy and Thanh [17] presented and compared four different types of mobile applications native, mobile widgets, mobile web, and HTML5 respectively. The research works of [18]–[21] analyzed several web and hybrid mobile application development frameworks. For example, Palmieri *et al.* [18] presented a detailed comparison of four different cross-platform tools (i.e., RHODES, PhoneGap, DragonRAD and MoSync respectively) to develop mobile applications on diverse mobile operating systems. Similarly, Masi *et al.* [22] suggest a framework to assist mobile application developers in selecting an appropriate technology based on the given context and requirements for the development of a mobile application.

The increasingly diverse demands of mobile applications motivated us to investigate and identify the challenges to assist mobile application development organizations in measuring and improving their readiness before starting development activities. To the best of our knowledge, no specific study (i.e., SLR and interviews-based empirical study) has been conducted to analyze the challenges of efficiently developing and managing mobile applications (native, web or hybrid).

Recently, in a survey study [1] with native mobile application developers and an exploratory study [2], [3] focused on investigating hybrid mobile application development. They concluded that the work so far done on mobile application

development is entirely anecdotal. One of the main research gaps identified by them [1]–[3] is that the current research works lack empirical studies on investigating native, web and hybrid mobile application development. The empirical study presented in this paper fills this gap by presenting the challenges of native, web and hybrid mobile application development through conducting SLR and interviews with real-world practitioners.

III. RESEARCH METHODOLOGY

To address the posed research questions, we followed two research approaches: SLR and the interviews. The SLR [23]–[25] was used as the primary method for data collection. The interviews were conducted to collect data from mobile application developers, based on their experience of the identified challenges and to confirm the findings of SLR. The two adopted research methods are discussed in detail in the following sections.

A. DATA COLLECTION VIA SYSTEMATIC LITERATURE REVIEW

We performed SLR [26]–[30] to identify and evaluate relevant published research work with the aim to analyze the posed research questions. Following the guidelines of [23] and [24] our SLR was conducted by a team of four researchers, i.e., three Ph.D. students and one academic staff member. All team members took participation in all the phases of the SLR. To minimize the personal bias and to improve the SLR process, inter-rater reliability tests were conducted at initial and final selection phases of the SLR process. The inter-rater reliability test is discussed in Section 3A.4). Our SLR execution [25], [31], [32] is done by following these steps:

1) SEARCH STRATEGY

We selected suitable search terms to ensure that no relevant article is missed in our study. We validated the selected keywords in research databases and the following synonyms found to be relevant to the topic.

Mobile Application Development = Mobile Application Development, Mobile Application Software Engineering, Mobile apps development, Mobile apps Software Engineering

Challenges = Challenges, problems, issues, hurdles, barriers, difficulties, complications, limitations, obstacles

We used Boolean operators to combine major search terms and constructed the following search terms after validating them through already known relevant research papers.

(Mobile Application Development OR Mobile Application Software Engineering OR Mobile apps development OR Mobile apps Software Engineering) AND

(Challenges OR problems OR issues OR hurdles OR barriers OR difficulties OR complications OR limitations OR obstacles)

We performed a thorough search in the following available academic databases to identify relevant articles published between 2006 and 2016.

TABLE 1. Quality assessment.

Quality Criteria	Score
Does the study discuss any barriers to mobile application development?	Yes =1 No =0
Are the findings and results explicitly mentioned in the study?	Yes =1 No =0
Are the arguments in study adequately presented and justified?	Yes =1 No =0
Is the study adequately referenced?	Yes =1 No =0

a. ACM Digital Library.
b. IEEE Xplore.
c. Science Direct.
d. Springer Link.
e. Google Scholar.

Since these databases have considerably different search criteria and capability, we accordingly adopted our search terms.

2) INCLUSION AND EXCLUSION CRITERIA

The authors applied the following inclusion criteria

a. Conference Proceedings, Magazines, and Journals published during 2006-2016.
b. Studies focused on challenges or problems of mobile application development (native, web or hybrid).

The authors applied the following exclusion criteria:

a. Papers published before 2006.
b. Manuscripts published in a language other than English.
c. White papers and technical reports.
d. Graduation, Master and Ph.D. thesis are excluded.
e. Textbooks, both print, and e-forms.
f. Studies published in other domains of knowledge, e.g., Chemical Engineering.

3) QUALITY ASSESSMENT CRITERIA

For any paper to pass the initial selection phase, a quality assessment criterion was set. We set four quality assessment criteria for the paper as depicted inTABLE 1. Thus, a paper which achieved a quality score of 4 was included in the final selection.

4) STUDY SELECTION, EXTRACTION AND ANALYZING THE DATA

The selection criterion of relevant papers is done in two stages initial selection and final selection. In initial selection criteria, the title and abstract of the papers are read. All those publications are removed which are entirely irrelevant explicitly from the name of their titles and abstract. In a final selection from the initially selected list of papers, the decision is made upon reading the entire papers thoroughly that meet the selection criteria. These two stages study selection criteria were performed by one of the authors of this paper. The total number of papers retrieved after performing a search using

TABLE 2. Search results.

Resource	Total Results	Initial Selection	Final Selection
IEEE Xplore	345	75	26
ACM Digital Library	145	38	16
Science Direct	53	18	2
Springer Link	819	33	9
Google Scholar	800	43	25
Total	2162	207	78

the defined search strings in the selected academic databases is shown inTABLE 2. For Google Scholar we considered only top 800 retrieved results.

For a paper to be included in our study, we primarily assessed the paper thoroughly through the four quality assessment criteria set as depicted in TABLE 1. We finally selected 78 papers which met our inclusion and quality criteria as shown in APPENDIX 1. For addressing our research questions, the extracted data from the selected papers were: authors, type of publication, paper title, publisher, date of publication, type of mobile applications, and type of mobile application development challenges.

We performed inter-rater reliability test to minimize the researcher's study selection bias. In inter-rater reliability test process, three independent reviewers randomly chose ten publications each from the 'total results' list and carried out the initial selection process. Likewise, the three independent reviewers also chose randomly ten publications each from the 'initial selection' list and carried out the final selection process.

We employed non-parametric Kendall's coefficient of concordance (W) [33] to assess the inter-rater agreement between three independent reviewers. Kendall's coefficient of concordance (W) value has a scale between 0 and 1, where 0 depicts full disagreement, and 1 depicts full agreement. In our study, Kendall's coefficient of concordance (W) for the ten randomly chosen papers from 'total results' was 0.83 ($p = 0.007$), which depicts a strong level of agreement between the results generated by the primary researchers and the three independent reviewers. Besides, Kendall's coefficient of concordance (W) for the ten randomly chosen papers from the 'initial results' list was 0.91 ($p = 0.003$), which also depicts a strong level of agreement between the results generated by the primary researchers and the three independent reviewers. Based on the depicted significant agreement between the authors and the independent reviewers we did not change the 'total results' and 'initial results.'

Grounded theory-based coding method [34], [35] offers an analytical approach in which concepts are recognized, labeled and semantically characterized through a thorough assessment of data. We employed Grounded Theory-based coding method to review the research articles and conceptualize the pivotal challenges. We recognized, named and grouped the associated challenges to general categories. Besides, similar or associated challenges were semantically matched and grouped into appropriate categories. The data synthesis phase was carried out in a team, and as a consequence of the extraction phase, a list of development challenges or problems from the 78 papers was generated. At first, 15 challenges or problems categories were identified. Three researchers thoroughly assessed each category to minimize inter-person bias and increase the validity of the identified problems or challenges and their categories. After the identified 15 challenges categories were assessed and validated, the associations between the categories were identified, and the correlated categories were merged into nine major categories. Each main group or category represents a mobile application development challenge or problem.

B. DATA COLLECTION VIA INTERVIEWS

Our SLR findings served as an input to develop an empirical structured interview questionnaire to investigate whether the challenges identified in the literature currently exist in mobile application development industry. An empirical survey is an appropriate method for gathering, self-reporting qualitative and quantitative data from a large number of respondents [36] via using specific techniques such as interviews and questionnaires [37], [38]. We designed closed-ended format interview questionnaire (enabled practitioners to specify additional challenges if any) as a data collection instrument to gather data from expert mobile application developers. The interview questionnaire was developed based on the nine identified challenges from the SLR as shown in APPENDIX 2. The interview participants were instructed to mark each development challenge as either 'Strongly Agree (SA),' 'Agree (A),' 'Strongly Disagree (SD),' 'Disagree (D),' or 'Not Sure (NS).'

The interview questionnaire was validated using a pilot study involving six experienced developers from different mobile application development organizations. The final version of interview questionnaire was developed based on the feedback from this evaluation. Our interview questionnaire has two sections: section one is about the demographic data of the interviewees and section two presents the challenges in mobile application development. All the interviewees were ensured about the confidentiality of information and data before their participation in interviews. The data was solely used for research purposes and will not be shared with anyone under any circumstances.

1) DATA SOURCES

The objective of this study was to collect and investigate the real challenges faced by mobile application developers when they develop mobile applications (native, web or hybrid). Therefore, it was necessary to gather data from various practitioners involved in mobile applications development. We recruited interview participants through our contacts and colleagues [36]. We recruited a total of 34 interview participants and scheduled 30-45 minutes time slot for conducting interviews based on their availability.

The participants were from Asia and developed a diverse range of mobile applications, e.g., entertainment, social networking, maps, games, weather, shopping, travel, and

TABLE 3. List of the Challenges Identified by SLR.

Challenges	Freq. (n=78)	%
Fragmentation	36	46
Testing	34	44
User Experience	42	54
Reuse of Code	12	15
Compatibility	36	46
Lack of Tools Support	11	14
Lack of Expertise	11	14
Change Management	21	27
Security	3	4

health. Furthermore, the majority of the participants have 2-5 years experience in mobile applications development. The detailed demographic information of participants is given in APPENDIX 2.

2) INTERVIEWS DATA ANALYSIS

We utilized frequency analysis method [39]–[43], the most widely adopted method to efficiently organize the descriptive data. In this technique, frequency tables were used to represent the frequencies and percentages of the data. Frequencies analyses are very useful not only for analyzing groups of variables but can also be used for both ordinal and numerical data. To evaluate the significance of the identified challenges, we counted the frequency of the number of agreements on each barrier or challenge and then matched concerning the other barriers or challenges. This method has been widely adopted by several researchers in a variety of software engineering areas [44]–[46].

IV. RESULTS

A. CHALLENGES IDENTIFIED FROM SLR

The total number of results retrieved from the SLR after performing the search in the academic databases is shown in TABLE 2. After careful steps of scrutiny and performing inclusion and exclusion criteria, 78 studies were selected (i.e., n = 78). We assessed each publication and extracted nine critical challenges common in native, web and hybrid application development. The common identified nine challenges of mobile application development (native, web, hybrid), along with their frequencies, are shown in TABLE 3.

After carefully reading each selected paper, a native, web and hybrid mobile applications categorization was made for the identified challenges. A total of 62 studies were related to native and the web mobile applications development each, while 57 studies were related to hybrid mobile applications development as shown in TABLE 4. The list of selected primary studies is shown in APPENDIX 1. We performed the Chi-Square test on the mobile application development challenges to identify the viewpoints of these three types of mobile applications (native, web, and hybrid) as shown in TABLE 5.

TABLE 5 answers our first research question (RQ1). A comparison of the challenges identified in native, web and hybrid mobile applications development indicates that there are slighter more differences than similarities between the challenges. Our findings show that 'fragmentation (58%, 8% and 4%), 'testing' (50%, 47% and 47%), 'user experience' (11%, 48% and 44%), 'compatibility' (5%, 52% and 21%) and 'change management' (32%, 8% and 11%) are the most common challenges in native, web and hybrid mobile applications development respectively.

We have identified five significant differenced (i.e., $p < 0.05$) between native, web and hybrid mobile applications, as shown in TABLE 5. The results show that in native mobile application development developers are more concerned (58%) about fragmentation challenge than in web (8%) and hybrid (4%) mobile application development. The challenge of user experience is of more concern for developers in web applications (48%) than in native (11%) and hybrid (44%) mobile applications development. The challenge of reuse of code is of more concern for developers in native (19%) than in web (2%) and hybrid (2%) mobile applications development. The issue of compatibility is very challenging for developers in the web (52%) than in native (5%) and hybrid (21%) mobile applications development. Similarly, the issue of change management is of more concern for developers in native (32%) than in the web (8%) and hybrid (11%) mobile applications development.

1) CHALLENGES IN NATIVE APPLICATIONS

a: FRAGMENTATION

This is one of the most commonly reported challenges faced by native mobile application developers, appearing in 58% of the identified literature. The fact that, each mobile platform is different from others having its graphical user interfaces, standards, programming languages, API's, capabilities and SDK. The fragmentation issues occur not only across platform but also within the same platform, e.g., specific devices exist having distinct properties, i.e., memory, speed, and graphical resolutions. Another issue faced due to fragmentation is the portability, i.e., does not easily translate to another platform easily. To develop a native application having support for each platform is very challenging for the industry due to additional developer's skill set, costs and effort [1], [13].

b: TESTING

The second most frequently mentioned challenge in our study is "Testing" (50%). This challenge is prevalent in native application development not only due to performing for each platform separately but also due to lack of automated tool support, i.e., testing is mostly done manually. Some of the specific testing issues faced reported in the literature are checking consistency across platforms, API, developers are testers too, mobile-specific features, usability, handling rapid changes, and handling crashes [1], [7].

TABLE 4. List of selected primary studies for native, web and hybrid mobile applications.

Mobile apps types	Primary studies
Native	S2,S3,S4,S5,S6,S7,S8,S9,S11,S12,S13,S14,S15,S16,S17,S18,S20,S21,S23,S24,S25,S26,S28,S32,S33,S34,S35,S36,S37,S38,S39,S40, S41,S42,S43,S44,S45,S46,S49,S50,S51,S52,S53,S54,S55,S56,S57,S58,S59,S61,S62,S64,S67,S68,S69,S70,S71,S72,S73,S75,S76,S78
Web	S1,S2,S3,S4,S6,S7,S9,S11,S12,S13,S14,S16,S17,S18,S19,S20,S21,S22,S23,S24,S25,S26,S28,S29,S34,S35,S36,S37,S38,S39,S40,S41, S42,S43,S44,S45,S46,S47,S49,S50,S52,S53,S54,S55,S56,S57,S58,S59,S60,S61,S62,S63,S64,S67,S68,S70,S73,S74,S75,S76,S77,S78
Hybrid	S1,S2,S3,S5,S6,S7,S8,S9,S10,S11,S12,S14,S15,S16,S17,S18,S19,S20,S21,S22,S25,S26,S27,S30,S31,S34,S36,S38,S39,S40,S41,S42, S44,S45,S46,S48,S49,S52,S53,S54,S55,S57,S59,S60,S62,S63,S64,S65,S66,S67,S68,S70,S72,S73,S75,S77,S78

TABLE 5. Chi Square analysis of challenges with respect to native, web and hybrid applications (SLR).

Challenges	Native (n=62)		Web (n=62)		Hybrid (n=57)		Chi-square Test (Linear-by-Linear Association) $\alpha = .05$		
	Freq.	%	Freq.	%	Freq.	%	X^2	df	p
Fragmentation	36	58	5	8	2	4	49.731	1	.000
Testing	31	50	29	47	27	47	.085	1	.770
User Experience	7	11	30	48	25	44	14.437	1	.000
Reuse of Code	12	19	1	2	1	2	13.206	1	.000
Compatibility	3	5	32	52	12	21	4.616	1	.032
Lack of Tools Support	8	13	3	5	7	12	.024	1	.878
Lack of Expertise	8	13	3	5	7	12	.024	1	.878
Changes Management	20	32	5	8	6	11	10.183	1	.001
Security	2	3	3	5	2	4	.008	1	.927

c: CHANGE MANAGEMENT

Approximately 32% of the research articles mentioned: ''Change Management'' as amongst one of the difficult challenge faced by native application developers. Native apps development itself is challenging because developing the same app across heterogeneous platforms. It becomes even more challenging when some requirements (functional or non-functional) changes or updates are requested in the same app from specific customers. The changes in the app could be due to improvements, unsatisfied customers, unclear and imprecise requirements implemented. Thus, developers are faced with the enormous challenge of updating or changing the same native app across multiple platforms. It not only requires extra efforts, costs but also needs the expertise of different platforms tools/languages simultaneously [6], [7].

d: REUSE OF CODE

In our study ''Reuse of Code'' challenge is reported in approximately 19% of the identified papers. Native applications are developed for each platform separately having different user interfaces, constraints, and API, thus, less reuse of code. Mobile app developers have to write the code from scratch for each platform separately because reusing the existing code results with compromised quality, functionalities and unsatisfied customers. Thus, there is a need for tool support which can enable native app developers to reuse code or frameworks [1], [7].

e: LACK OF TOOLS SUPPORT

This challenge has been reported in approximately 13% of the selected literature. Native applications are developed for each platform separately which is quite challenging for developers to re-develop the same application for other platforms. There is a need for uniform development tools support which can enable developers to adopt the native application for multiple platforms with less effort [47], [48].

f: LACK OF EXPERTISE

''Lack of Expertise'' challenge has been mentioned in 13% of the literature. Native application development requires a separate set of development tools and expertise for each platform separately. Thus, developers are faced with the challenge of having expertise across all platforms tools [49], [50].

g: USER EXPERIENCE

In our study ''User Experience'' challenge is reported in 11% of the articles. Native apps are known for their better performance and user experience. However, providing better user experience and performance is very challenging for developers due to platforms difference in user interfaces, behavioral consistency, and slow response time especially in the web technology [1], [14].

h: COMPATIBILITY

''Compatibility'' issue faced by native developers is very less, only reported in approximately 5% of the identified literature. Compatibility problems occur because each platform has specific constraints on the capabilities provided, i.e., Android (open source) vs. iOS (closed source). Thus, developers are faced with compatibility problems for developing native apps for multiple platforms, e.g., reduced support for HTML5 in Android different versions and browsers [1], [13].

i: SECURITY

"Security" is the least challenge reported in 3% of the literature. Ensuring security of the mobile application is quite challenging due to the open characteristic of mobile platforms; prone to the installation of new "malware" applications considerably easy ultimately can disturb the normal operation of the device, including the secret transfer of data through such an application [7].

2) CHALLENGES IN WEB APPLICATIONS

a: COMPATIBILITY

"Compatibility" is the peremptory challenge reported in 52% of the identified literature. The developers are faced with compatibility issue due to constraints on platform capabilities, i.e., less access to device API or features. Thus, developing web applications across heterogeneous platforms having fewer performance issues is quite challenging for developers [13], [14].

b: USER EXPERIENCE

In our study "User Experience" is the second frequent severe challenge reported in about 48% of articles. Every platform has varied user interfaces sizes and access to platform features which ultimately affects the performance and user experience of web applications built. Developers are faced with minimizing such issues to satisfy their customers by providing excellent quality web applications having better performance and user experience [13], [14].

c: TESTING

"Testing" is the third frequent challenge reported in 47% of the identified literature. Testing web applications is particularly challenging due to several reasons, e.g., dynamic loading, heterogeneity in devices, limited resources, limited access to device features, test automation tools, complexity, context or environment changes, and test coverage criteria [51], [52].

d: FRAGMENTATION

This challenge has been reported in 8% of the identified research studies. Fragmentation in web application development is not a big challenge compared to the native application development. However, developers are continuously faced with fragmentation and portability issues due to heterogeneity in platforms support and restrictions [7], [14].

e: CHANGE MANAGEMENT

In our study "Change Management" issue has been reported in 8% of the literature which is comparatively less challenging. The change in web applications could be due to several reasons; new feature requests, updates, and fixing bugs. However, maintenance or update is still challenging in web application development due to heterogeneity in platforms, lack of resources (extra effort and cost required), and lack of testing support [6], [52].

f: SECURITY

"Security" is the less mentioned challenge in 5% of the identified literature. Mobile web applications are more prone to security issues due to limited access to device features. Thus, more challenging for developers to ensure secure web applications due to lack of full coverage testing [7], [48].

g: LACK OF TOOLS SUPPORT

In our study, this challenge is the less frequently mentioned in 5% of the literature. Web applications are aimed to serve multiple platforms; however, lack of full tools support is one of the significant obstacles to fulfill this goal. The tools support are needed in situations specifically for; translating the applications from one platform to another platform, addressing compatibility issues, automatic code reuse, debugging/testing support, and user interface designer [16], [47].

h: LACK OF EXPERTISE

"Lack of expertise" is also amongst the less mentioned challenges in the literature (5%). However, lack of expert developers is still a challenging issue. Mobile web applications are targeted to support multiple platforms simultaneously but require expertise to efficiently translate from one platform to another without compromising the quality of applications. Thus, need expert knowledge of not only multiple platforms (API, GUI) but also of required development tools [16], [47].

i: REUSE OF CODE

"Reuse of Code" is the least reported web application development challenge in the literature (2%). There are lots of efforts spent on tools to minimize the development effort to develop near to native applications across several platforms by translating native applications interfaces. Nevertheless, this method does not work well due to restriction levels on mobile device's API. Thus, developers are in need of tools and techniques which could enable them to reuse the existing frameworks for translating from one platform to the other [6].

3) CHALLENGES IN HYBRID APPLICATIONS

a: TESTING

"Testing" challenge is the most severe challenge reported in 47% of studies. Hybrid applications are targeted to run across platforms, thus, testing each aspect in such applications quite challenging for developers. Some of the reasons behind these challenges are, e.g., lack of automated testing tools support, rapid changes in requirements, lack of access to platforms features, changes in contextual or environmental factors of application, complexity, integration issues, conformance issues, diversity in user interfaces, heterogeneous devices or platforms, operating systems diversity, lack of resources (separate expert testers, effort, cost), lack of standards, and lack of real environment for testing [15], [53].

b: USER EXPERIENCE

This challenge is the second frequent mentioned challenge in the literature (44%). Hybrid applications are not executed like native applications. Therefore, developing these applications have several issues due to different user interfaces, lack of access to device features, and contextual factors, which ultimately affects the performance and user experience (usability, response time, and reliability) of hybrid applications [5], [13].

c: COMPATIBILITY

''Compatibility'' issue in hybrid application development is the third frequent challenge as reported in 21% of the identified literature. Hybrid applications also have compatibility issues due to platform-specific constraints or access to API when translating from one platform to another. Also, unlike native applications hybrid applications lack full access to device features, this is quite challenging for developers to tackle individually in translating large applications from one platform to the other [3], [54].

d: LACK OF TOOL SUPPORT

''Lack of Tool Support'' was reported in 12% of research studies. Developing hybrid applications are quite challenging since it has both native and web applications characteristics. One of the main reasons it has not achieved success is due to lack of availability of sophisticated tools support which can enable developers to develop such applications. Specifically, in translating the hybrid applications from one platform to another, supporting reuse of code, handling compatibility issues, and full testing support [16], [50].

e: LACK OF EXPERTISE

Approximately 12% of studies cited ''Lack of Expertise'' as a significant challenge in hybrid application development. Developers are always faced with lack of expertise in development tools (translating code efficiently from one platform to another) and knowledge of each platforms API or features [47], [50].

f: CHANGE MANAGEMENT

''Change Management'' challenge is reported in 11% of the identified literature studies. The frequency of the change management challenge is less reported in the literature. Nevertheless, managing change requests is quite difficult to tackle for developers. The reasons for change request could be due to new features (functional or non-functional) from customers, fixing existing bugs, and change in operating systems versions. The issue of handling change in native part of the hybrid application is very challenging. Thus, the maintenance of hybrid applications needs extra resources (testing and development tools, expertise, effort, and costs) due to cross platforms development [13], [52].

g: FRAGMENTATION

In our study ''Fragmentation'' challenge is mentioned in 4% of the articles. Hybrid applications are aimed to overcome the shortcomings of both native and web applications. However, they still have some portability issues due to heterogeneity in platforms features support [13], [54].

h: SECURITY

''Security'' is amongst one of the least reported challenge in the literature (4%). The web part of the hybrid application is prone to security threats due to its open and dynamic interaction. Thus, ensuring the security of hybrid applications is quite challenging due to open characteristics of mobile platforms and testing coverage criteria [7].

i: REUSE OF CODE

''Reuse of Code'' is the least mentioned challenge in the literature (2%). However, we consider this as one of the significant challenges that need to be tackled by academia and industry. Like native and web applications development developers are in need of adequate tools or techniques which could enable to reuse their same code across platforms without compromising the quality of application developed [6].

B. CHALLENGES IDENTIFIED FROM INTERVIEWS

In the second step of our research, we designed and conducted interviews with practitioners based on the challenges identified in the SLR. The practitioners' responses in interviews aim to answer our RQ2.

TABLE 6 depicts the rankings of the challenges identified in our empirical study. It explains the practitioners' real experiences to assess a particular challenge of mobile application development. TABLE 6 is categorized into three separate columns, i.e. 'Positive' (i.e., agree and strongly agree), 'Negative' (i.e., disagree and strongly disagree) and 'Neutral' (i.e., not sure). The respective values in the 'Positive' column depict the percentage of practitioners who agree with the identified challenges of mobile applications development, whereas the respective values in the 'Negative' column depict the percentage of practitioners who think the challenge might not be present during mobile applications development.

It is interesting to observe that real-world practitioners support the research as the majority of the 34 practitioners, who participated in our interviews, agreed that all the nine identified challenges could have a considerable impact on mobile applications development (native, web, hybrid) success. It is quite apparent from the results in the 'Positive' column where most of the values are above 50%. The practitioners feel that 'testing' is a major challenge (i.e., 79%) in mobile application development. It is true because of lack of automated test tools, professional testers, awareness, and fragmentation of devices. As a result, testing can become a major challenge if there are no proper measures taken by organizations during mobile application development. Our results also show that 'change management' (i.e., 74%) is the second most significant challenge in mobile application development. We believe this is challenging due to heterogeneity across platforms, extra effort, and costs are required. In addition to this, the other significant challenges are 'lack of tools support,' 'lack of expertise,' and 'fragmentation,' (i.e., $>60\%$),

TABLE 6. Summary of Challenges from Interviews.

Challenges	Real-World Practice Observation (n=34)							
	Positive			Negative			Neutral	
	Strongly Agree	Agree	%	Strongly Disagree	Disagree	%	Not Sure	%
Fragmentation	19	2	62	6	7	38	0	0
Testing	19	8	79	2	5	21	0	0
User Experience	4	9	38	14	5	56	2	6
Reuse of Code	6	10	47	9	8	50	1	3
Compatibility	4	4	24	12	13	73	1	3
Lack of Tools Support	16	8	71	3	7	29	0	0
Lack of Expertise	9	14	68	3	8	32	0	0
Change Management	18	7	74	3	6	26	0	0
Security	3	4	21	7	18	73	2	6

TABLE 7. Analysis of challenges concerning native, web and hybrid categories (interviews).

Challenge	Occurrence in interviews (n=34)																	
	Native (n=23)					Web (n=4)					Hybrid (n=7)					Chi-square (Linear-by-linear Association) α = .05		Test
	SA	A	D	SD	NS	SA	A	D	SD	NS	SA	A	D	SD	NS	X^2	df	P
Fragmentation	17	2	2	2	0	1	0	1	2	0	1	0	4	2	0	9.516	1	.002
Testing	16	2	3	2	0	2	1	1	0	0	1	5	1	0	0	.932	1	.334
User Experience	1	4	3	14	1	2	1	1	0	0	1	4	1	0	1	5.723	1	.017
Reuse of Code	4	10	3	6	0	1	0	1	1	1	1	0	4	2	0	1.574	1	.210
Compatibility	1	2	8	11	1	2	1	1	0	0	1	1	4	1	0	4.141	1	.042
Lack of Tools Support	13	5	3	2	0	1	1	2	0	0	2	2	2	1	0	1.835	1	.176
Lack of Expertise	7	8	6	2	0	1	2	1	0	0	1	4	1	1	0	.095	1	.758
Changes Management	16	4	2	1	0	1	1	1	1	0	1	2	3	1	0	7.297	1	.007
Security	1	1	15	5	1	1	1	1	1	0	1	2	2	1	1	.973	1	.324

as depicted by the respective results in the positive column of TABLE 6.

Furthermore, we also observe some additional challenges from the interviews not found in our SLR. The additional challenges revealed in interviews with practitioners are; 'lack of training,' 'lack of teamness,' 'lack of knowledge management' and 'lack of communication' also have an impact on mobile application development success. More than 50% of the interview participants considered it as a challenge and specified it in the extra option given to them. We believe that these four additional challenges have an impact on the success of mobile application development like any other software development projects as reported in several research studies, e.g., [39], [42], and [55]. We did not specify the additional challenges revealed by practitioners in tables (TABLE 6, TABLE 7 and TABLE 8) since it was not mentioned by all practitioners and may have an impact on accurate statistical calculations.

Our findings depict that most of the practitioners' either strongly agreed or agreed with the SLR findings - specifying that there are more similarities than differences between practitioners regarding what is a challenge in native, web or hybrid applications development. We have identified four significant differences (i.e., $p < 0.05$) between native, web and hybrid applications development, as depicted in TABLE 7. It is worth stating that 'fragmentation' issue is more severe (83%) in native than web (25%) and hybrid (14%) applications development. Likewise, the challenge of 'change management' is more critical in native (87%) than the web (50%) and hybrid (43%) applications development. There is also a significant difference between native, web and hybrid mobile applications development about the challenge of 'user experience.' This challenge is more critical on the web (75%) and hybrid (71%) than the native (22%) mobile applications development. Similarly, the challenge of 'compatibility' is more severe on the web (75%) than the hybrid (29%) and native (13%) mobile applications development.

C. COMPARISON OF THE SLR AND THE INTERVIEW RESULTS

This section outlines the comparative analysis of the challenges identified by the SLR and the interviews with practitioners. It will support in clearly understanding the similarities and differences among the outcomes of the two research approaches adopted. TABLE 8 demonstrates an overview of the average rank of challenges identified through the SLR and the interviews. The data acquired from the SLR has not been subjected to any categorization whereas the data acquired from the interviews were categorized as Strongly Agree, Agree, Disagree, Strongly Disagree and Not Sure. It is interesting to observe that some additional challenges from interviews were revealed not found in our SLR. The additional challenges revealed in interviews with practitioners are 'lack of training,' 'lack of teamness,' 'lack of knowledge management,' and 'lack of communication.' We ignored to include the newer challenges in the ranks between SLR and interview since they were not present in the list of challenges identified in SLR.

TABLE 8. Comparison of Challenges' Ranks between SLR and interviews.

Challenges	Occurrence in SLR (n=78)		Positive challenges in interviews (n=34)	
	%	Rank	%	Rank
Fragmentation	46	2.5	62%	5
Testing	44	4	79%	1
User Experience	54	1	38%	7
Reuse of Code	15	6	47%	6
Compatibility	46	2.5	24%	8
Lack of Tools Support	14	7.5	71%	3
Lack of Expertise	14	7.5	68%	4
Change Management	27	5	74%	2
Security	4	9	21%	9

TABLE 9. Correlations Rank across the Data of SLR and interviews.

			SLR	Interviews
Spearman's rho	SLR	Correlation Coefficient	1.000	-.034
		Sig. (2-tailed)	.	.932
		N	9	9
	Interviews	Correlation Coefficient	-.034	1.000
		Sig. (2-tailed)	.932	.
		N	9	9

TABLE 10. Group Statistics.

	Type	N	Mean	Std. Deviation	Std. Error Mean
Factors	SLR	9	22.89	14.287	4.762
	Interviews	9	18.22	7.496	2.499

TABLE 11. Independent Samples t-Test.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Factor	Equal variances assumed	9.135	.008	.868	16	.398	4.667	5.378	-6.734	16.068
	Equal variances not assumed			.868	12.095	.402	4.667	5.378	-7.041	16.374

To measure the significance of the similarity in the challenges identified from SLR and the interviews based empirical study, we did a correlation analysis test. TABLE 9 illustrates the Spearman's rank-order correlation. The Spearman's correlation coefficient, rs is -.034, whereas the value of $p = 0.932$. The $rs = -.034$ depicts the weak negative correlation between the ranks obtained from the SLR and interviews-based empirical study, i.e., when the rank of the challenges identified via SLR increases then the rank of the challenges identified via interviews slightly decreases and vice versa. The value of p is $.932 > 0.05$ depicts that Spearman's rank-order correlation is not statistically significant.

To compare the mean differences of SLR and interviews, we performed the independent t-test additional to the Spearman's Rank order Correlation, as illustrated in TABLE 10 and TABLE 11 respectively. It can be seen in TABLE 11 the Levene's Test is significant (i.e., $0.008 < 0.05$), thus, we have to consider the corresponding values of the option "equal variances not assumed." Considering this assumption, the outcomes of t-test (i.e., $t = 0.868$, $p = 0.402 > 0.05$) depicts that there is no significant difference between the findings of SLR and interviews since the value of the mean is not significantly different in two data sets depicted in TABLE 10. The mean value in SLR is 22.89, and in interviews, it is 18.22. It demonstrates the level

of agreement present between the SLR and the real world practice.

D. MAPPING OF CHALLENGES TO 11 KNOWLEDGE AREAS OF SWEBOK (RQ4)

Software Engineering Body of Knowledge (SWEBOK) [56] has identified in a total of 15 knowledge areas of software development. Each knowledge area describes the critical competencies that software developers must develop and possess. It is worth mentioning that all the knowledge areas of SWEBOK are essential. However, for this study, we considered only 11 knowledge areas of SWEBOK for mobile application development. We decided to map all the identified challenges to 11 knowledge areas of software development to inform practitioners of what problems or challenges need to be tackled in each knowledge area for successful mobile application development (native, web or hybrid).

The finally selected 13 challenges (nine common in SLR and interviews along with four newer challenges identified in interviews) were examined to identify the relevant software development knowledge area. Three researchers took participation in the mapping process in which we labeled and grouped the associated challenges into a relevant SWEBOK knowledge area. Our mapping illustrates that most of the challenges are related to software engineering professional practice, software design, software construction and software quality knowledge areas as depicted in TABLE 12. The challenges were mapped to only seven knowledge areas of SWEBOK while none of the challenges was mapped to the remaining knowledge areas, e.g., software maintenance, software configuration management, and software engineering process, as can be seen in TABLE 12.

This mapping of identified challenges (SLR and interviews) has both academic and real-world practical implications. Based on the SLR and interviews, this study provides a set of development challenges in mobile application development, which serves as a knowledge-base for both academic and real-world practitioners. These mapping of challenges are essential for academia so that researchers in future can emphasize in high priority areas of mobile application development. We also expect that the mapped challenges can be beneficial to practitioners for devising strategies and policies to overcome these challenges in mobile application development.

V. SUMMARY AND DISCUSSION

In this paper, we identified the challenges of mobile application development (native, web and hybrid). The identified challenges characterize some key development knowledge areas where real-world practitioners should concentrate their attention to have considerable control over these challenges or problems for successful and efficient mobile application development. To analyze the severity of a specific challenge, we employed the following criterion:

- The challenge is deemed significant if it is mentioned in the literature with a frequency percentage of >=40%, or if the challenge is answered as strongly agree or agree in the interviews with a frequency percentage of >=40%.

TABLE 12. SWEBOK knowledge areas and identified challenges.

	Knowledge Areas		Challenges
1.	Software Requirements	1.	Change Management
2.	Software Design	2.	Fragmentation
		3.	Compatibility
3.	Software Construction	4.	Reuse of Code
		5.	Lack of Tools Support
4.	Software Testing	6.	Testing
5.	Software Maintenance		
6.	Software Configuration Management		
7.	Software Engineering Management	7.	Lack of Expertise
8.	Software Engineering Process		
9.	Software Engineering Models and Methods		
10.	Software Quality	8.	User Experience
		9.	Security
11.	Software Engineering Professional Practice	10.	Lack of Training
		11.	Lack of Teamness
		12.	Lack of Knowledge Management
		13.	Lack of Communication

This severity of challenge criterion has been used in several research studies [44], [46], [57], [58]. Based on the severity of analysis criterion, TABLE 12 depicts the summary of the challenges identified in the SLR and interviews.

Our results show that 'Fragmentation,' 'Testing,' 'User Experience,' and 'Compatibility' are critical in native, web or hybrid mobile application development (RQ1).

For our RQ2, using the criterion above, if we take into consideration the positive side (i.e., both strongly agree and agree). Then the identified challenges considered critical are fragmentation, testing, reuse of code, lack of tools support, lack of expertise, and change management as they have been mentioned by >=40% of the participants in interviews.

To address our RQ3, we have found two common critical challenges in both SLR and interviews as given in TABLE 12. We performed two tests, namely t-test and Spearman correlation as depicted in TABLE 9, TABLE 10 and TABLE 11. The results of the tests illustrate that there is a weak negative correlation between the ranks obtained from the SLR and the interviews-based empirical study. The results obtained from our t-test (i.e., $t = 0.868$, $p = 0.402 > 0.05$) shows that there is no significant difference between the findings of SLR and interviews. These results specify that academia and real-world practitioners are aligned and share the similar challenges.

To address RQ4, we have mapped the identified challenges to 11 knowledge areas of SWEBOK. Our mapping depicts that most of the challenges are related to software design, software construction, software quality and software engineering professional practice and no challenges were mapped to the remaining knowledge areas, e.g., software maintenance, software configuration management, and software engineering process, as depicted in TABLE 12.

TABLE 13. Summary of results.

Research Question	Summary of Answers
RQ1: What development challenges, as identified in the literature, are specifically related to native, web or hybrid mobile applications?	• 'Fragmentation' is a more critical challenge in native (58%) than in web and hybrid (8%, 4%). • 'Testing' is critical in all types of mobile applications native, web and hybrid (50%, 47%, 47%) respectively. • 'User Experience' is more critical in the web and hybrid (48%, 44%) than native (11%) mobile applications. • 'Compatibility' is more critical in the web (52%) than in native and hybrid (5%, 21%) mobile applications. • We have found 'Fragmentation,' 'User Experience,' 'Reuse of Code,' 'Compatibility,' and 'Change Management' statistically significant differences (i.e., $p<0.05$) between the native, web and hybrid mobile applications as depicted in TABLE 5.
RQ2: What development challenges, as identified in real-world practice, are specifically related to native, web or hybrid mobile applications?	• 'Fragmentation' is a more critical challenge native (83%) than in the web and hybrid (25%, 14%). • 'Testing' is a more critical challenge in hybrid (86%) than in native and the web (78%, 75%). • 'Reuse of Code' is a more critical challenge in native (61%) than in the web and hybrid (25%, 14%). • 'Lack of tools support' is a more critical challenge in native (78%) than in the web and hybrid (50%, 57%). • 'Lack of Expertise' is a more critical challenge in the web (75%) than in native and hybrid (65%, 71%). • 'Change Management' is a more critical challenge in native (87%) than in the web and hybrid (50%, 43%). • We have found 'Fragmentation,' 'User Experience,' 'Compatibility,' and 'Change Management' statistically significant differences (i.e., $p<0.05$) between the native, web and hybrid mobile applications as depicted in TABLE 7.
RQ3. Are there differences between the challenges identified in the literature and real-world practice?	• Our results show that 'Fragmentation' and 'Testing' are the common critical challenges in both data sets. • Our results show a weak negative correlation between the ranks obtained from the SLR and the interview-based empirical study (($rs(9)= -.034$)). Besides, the Spearman rank-order correlation is also not statistically significant ($p=0.932>0.05$). • The results obtained from our t-test (i.e., $t = 0.868$, $p = 0.402 > 0.05$) depicts that there is no significant difference between the findings of SLR and interviews.
RQ4. What challenges are specifically related to the 11 knowledge areas of SWEBOK?	• We have mapped the identified challenges to 11 knowledge areas of SWEBOK. Our mapping depicts that most of the challenges are related to software design, software construction, software quality and software engineering professional practice and no challenges were mapped to the remaining knowledge areas, e.g., software maintenance, software configuration management, and software engineering process, as depicted in TABLE 12.

VI. LIMITATIONS

The scope of the SLR was limited to overall development challenges in mobile application development. We limited our SLR study to five research digital libraries (i.e., ACM Digital Library, IEEE Xplore, Science Direct, Springer Link and Google Scholar). However, there are other related research publication databases which we did not consider in this study that may have relevant research articles. Also, with the rapid rise in the number of research articles published on this topic, some recent articles might have been overlooked at the time of consolidating the results of our SLR. Nonetheless, we firmly believe that we have covered the available relevant research papers and the presented results are comprehensive.

Concerning the interviews, construct validity [59]–[61] emphases on whether or not the measurement scales precisely represent the attributes being measured. The factors considered in this work were obtained from extensive research literature [1], [3], [7], [47]. Internal validity [59], [62] is related to the overall assessment of the results. The outcomes of the pilot study minimized the internal validity threats as the factors encompassed in this study were the outcome of a detailed literature review and pilot questions.

In the interviews questionnaire, the participants were provided with close-ended questions to rank the identified challenges. The close-ended questions limit the participants' choice to only those critical barriers or challenges that are provided in the list. We tried to reduce this limitation by providing an open-ended text box to the participants so they could easily provide additional challenges in addition to those reported in the literature. Nevertheless, like the researchers of many research studies based on the experience data, e.g., [63]–[65], we are confident about the outcomes of the data collected from the mobile apps developers, who have good experience in mobile application development related activities.

Besides, external validity [59], [66]–[68] refers to the degree of generalization of the results appropriate for all domains. Our research findings possibly cannot be generalized because the mobile application development organizations are mainly Asian countries and small sample size. The empirical study does reflect limited sample and Asian region view. Thus, the outcomes of this research may not necessarily represent respondents from other countries and should be treated with caution due to small sample size and cross-cultural differences. Nevertheless, it is a first step towards identifying challenges interesting to different stakeholders and like similar empirical research studies, e.g., [55] and [69]–[77], we believe that the selected data sample was sufficiently representative.

It is quite challenging to find a bunch of mobile application development organizations volunteering to participate and invest time in interviews and empirical studies such as the one we conducted. We welcome the researchers to build on top of the results of this empirical study and conduct surveys with other mobile application development organizations to advance this body of knowledge. Replicating this study with a much more significant balanced sample from globally different mobile development organizations and in different domains can considerably help reduce this limitation. Thus, we leave this as a future work for the researchers to conduct further empirical studies to validate this generalization. Moreover, this study should be treated as an on-going work to be repeated and further extended in future as these challenges are quite dynamic.

TABLE 14.

Primary studies
S1: Xanthopoulos, S., & Xinogalos, S. (2013). *A Comparative Analysis of Cross-platform Development Approaches for Mobile Applications*. Paper presented at the ACM BCI'13.
S2: Amalfitano, D., Fasolino, A. R., & Tramontana, P. (2011). *A GUI Crawling-based technique for Android Mobile Application Testing*. Paper presented at the 2011 IEEE Fourth International Conference on Software Testing, Verification and Validation.
S3: Almasri, A. K. (2016). A PROPOSED HYBRID AGILE FRAMEWORK MODEL FOR MOBILE APPLICATIONS DEVELOPMENT. *International Journal of Software Engineering & Applications (IJSEA), 7*(2), 1-9.
S4: Do, K. B., SeungWeon, Y., & Seok, L. J. (2014). A Software Development Process for Mobile Applications. *Journal of Internet Computing and Services (JICS), 15*(4), 135-140.
S5: Willocx, M., Vossaert, J., & Naessens, V. (2015). *A Quantitative Assessment of Performance in Mobile App Development Tools.* Paper presented at the 2015 IEEE International Conference on Mobile Services.
S6: Zein, S., Salleh, N., & Grundy, J. (2016). A systematic mapping study of mobile application testing techniques. *The Journal of Systems and Software, 117*, 334-356.
S7: Ferdiana, R. (2012). Agile Software Engineering Framework for Evaluating Mobile Application Development. *International Journal of Scientific & Engineering Research (IJSER), 3*(12), 1-5.
S8: Singh, N. (2015). An comparative analysis of Cordova Mobile Applications vs Native Mobile Application. *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC), 3*(6), 3777-3782.
S9: Song, H., Ryoo, S., & Kim, J. H. (2011). *An Integrated Test Automation Framework for Testing on Heterogeneous Mobile Platforms*. Paper presented at the 2011 IEEE First ACIS International Symposium on Software and Network Engineering.
S10: Ahti, V., Hyrynsalmi, S., & Nevalainen, O. (2016). *An Evaluation Framework for Cross-Platform Mobile App Development Tools A case analysis of Adobe PhoneGap framework*. Paper presented at the International Conference on Computer Systems and Technologies-CompSysTech'16, Italy.
S11: Gupta, S. (2014). Addressing the Issues in Mobile Application Development. *International Journal of Computer Sciences and Engineering, 2*(7), 1-5.
S12: Pastore, S. (2015). Approaches and methodologies for mobile software engineering. *ACSIJ Advances in Computer Science: an International Journal, 4*(5), 14-22.
S13: Mikkonen, T., & Taivalsaari, A. (2011, 2011). *Apps vs Open Web The Battle of the Decade.* Paper presented at the Proceedings of the 2nd Annual Workshop on Software Engineering for Mobile Application Development, in connection with MOBICASE 2011.
S14: Villanes, I. K., Costa, E. A. B., & Dias-Neto, A. C. (2015). *Automated Mobile Testing as a Service (AM-TaaS)*. Paper presented at the 2015 IEEE World Congress on Services.
S15: Willocx, M., Vossaert, J., & Naessens, V. (2016). *Comparing performance parameters of mobile app development strategies*. Paper presented at the 2016 IEEE/ACM International Conference on Mobile Software Engineering and Systems, Austin, USA.
S16: Zhang, T., Gao, J., Cheng, J., & Uehara, T. (2015). *Compatibility Testing Service for Mobile Applications*. Paper presented at the 2015 IEEE Symposium on Service-Oriented System Engineering.
S17: Amalfitano, D., Fasolino, A. R., Tramontana, P., & Amatucci, N. (2013). *Considering Context Events in Event-Based Testing of Mobile Applications*. Paper presented at the 2013 IEEE Sixth International Conference on Software Testing, Verification and Validation Workshops.
S18: Sama, M., Elbaum, S., Raimondi, F., Rosenblum, D. S., & Wang, Z. (2010). Context-Aware Adaptive Applications Fault Patterns and Their Automated Identification. *IEEE TRANSACTIONS ON SOFTWARE ENGINEERING, 36*(5), 644-661.
S19: Ohrt, J., & Turau, V. (2012). Cross-Platform Development Tools for Smartphone Applications. *Computer*, 72-79.
S20: Charkaoui, S., Adraoui, Z., & Benlahmar, E. H. (2014). *Cross-platform mobile development approaches*.
S21: Amatya, S., & Kurti, A. (2014). *Cross-Platform Mobile Development Challenges and Opportunities*. Paper presented at the Advances in Intelligent Systems and Computing.

TABLE 14. ***Continued.***

S22: Gaouar, L., Benamar, A., & Bendimerad, F. T. (2016). Desirable Requirements of Cross Platform Mobile Development Tools. *Electronic Devices, 5*(1), 14-22.
S23: Huy, N. P., & Thanh, D. v. (2012a). *Developing Apps for Mobile Phones*. Paper presented at the 2012 7th International Conference on Computing and Convergence Technology (ICCCT), Seoul.
S24: Lan, Q., Chen, X., Song, G., & Parsaei, H. (2015). *Developing Cross-platform Mobile Applications for Real Time Remote Experiment*. Paper presented at the In Proceedings of E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2015.
S25: Vilkomir, S., Marszalkowski, K., Perry, C., & Mahendrakar, S. (2015). *Effectiveness of Multi-device Testing Mobile Applications*. Paper presented at the 2015 2nd ACM International Conference on Mobile Software Engineering and Systems.
S26: Heitkotter, H., Hanschke, S., & Majchrzak, T. A. (2013). *Evaluating Cross-Platform Development Approaches for Mobile Applications*. Paper presented at the WEBIST.
S27: Malavolta, I., Ruberto, S., Soruy, T., & Terragniz, V. (2015a). *End Users Perception of Hybrid Mobile Apps in the Google Play Store*. Paper presented at the 2015 IEEE International Conference on Mobile Services, New York, USA.
S28: Huy, N. P., & Thanh, D. v. (2012b). *Evaluation of mobile app paradigms*. Paper presented at the ACM MoMM 2012, Bali.
S29: Juntunen, A., Jalonen, E., & Luukkainen, S. (2013). *HTML 5 in Mobile Devices Drivers and Restraints*. Paper presented at the 2013 46th Hawaii International Conference on System Sciences.
S30: Malavolta, I., Ruberto, S., Soruy, T., & Terragniz, V. (2015b). *Hybrid Mobile Apps in the Google Play Store An Exploratory Investigation*. Paper presented at 2nd ACM International Conference on Mobile Software Engineering and Systems.
S31: VITOLS, G., SMITS, I., & ZACEPINS, A. (2014). *Issues of Hybrid Mobile Application Development with PhoneGap a Case Study of Insurance Mobile Application*. Paper presented at the Proceedings of the 11th International Baltic Conference, Baltic Data Base and Information Systems 2014.
S32: Kulesovs, I. (2015). *iOS Applications Testing*. Paper presented at the Proceedings of the 10th International Scientific and Practical Conference.
S33: Huynh, M., & Ghimire, P. (2015). Learning by Doing How to Develop a Cross-Platform Web App. *Journal of Information Technology Education: Innovations in Practice, 14*, 145-169.
S34: Holzer, A., & Ondrus, J. (2012). *MOBILE APP DEVELOPMENT NATIVE OR WEB?* Paper presented at the In proceedings of the Workshop on eBusiness (WeB'12).
S35: Charland, A., & LeRoux, B. (2011). Mobile Application Development Web vs Native. *Communications of the ACM, 54*(5), 49-53.
S36: Dehlinger, J., & Dixon, J. (2011). *Mobile Application Software Engineering Challenges and Research Directions*. Paper presented at the Proceedings of the Workshop on Mobile Software Engineering.
S37: Gao, J., Bai, X., Tsai, W.-T., & Uehara, T. (2014). Mobile Application Testing A Tutorial. *Computer*, 46-55.
S38: Kirubakaran, B., & Karthikeyani, V. (2013). *Mobile Application Testing Challenges and Solution Approach through Automation*. Paper presented at the Proceedings of the 2013 International Conference on Pattern Recognition, Informatics and Mobile Engineering (PRIME).
S39: Zein, S., Salleh, N., & Grundy, J. (2015). *Mobile Application Testing in Industrial Contexts An Exploratory Multiple Case Study*. Paper presented at the 14th International Conference on Intelligent Software Methodologies, Tools and Techniques (SOMET 2015), Naples, Italy.
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VII. CONCLUSION & FUTURE WORK

In recent years, mobile application development for smartphones has evolved tremendously due to ubiquity and popularity among end users. This rapid interest has drawn mobile application developers' attention over the last few years. As the industry of mobile application development is evolving rapidly, we were motivated to identify mobile application development (native, web and hybrid) challenges. We primarily adopted two research approaches to identify these challenges through conducting SLR and interviews with practitioners.

By adopting both research approaches, we identified nine challenges crucial to the success of mobile application development and four additional challenges (i.e., lack of training, lack of teamness, lack of knowledge management and lack of communication) from interviews not found in the literature.

TABLE 15.

Section 1: Demographic Questions

Contact Information:

Email: _____

Country	No. of Participants
Pakistan	**23**
China	**11**

Please specify your gender?

Gender	No. of Participants
Male	**33**
Female	**1**
Prefer not specify	

Please specify your age?

Age	No. of Participants
19 or younger	
20-29	**29**
30-39	**5**
40-49	
50 or older	
Prefer not specify	

Section 2: Technical Background Questions

How many years of work experience do you have in mobile application development:

Native Mobile Application	Mobile Web Application	Hybrid Mobile Application
Less than a year (5 participants)	Less than a year (2 participants)	Less than a year (4 participants)
1-3 years (14 participants)	1-3 years (2 participants)	1-3 years (1 participant)
4-6 years (4 participants)	4-6 years	4-6 years (1 participant)
More than 6 years	More than 6 years	More than 6 years (1 participant)

How do you categorize yourself or categorize your mobile application development experience as:

Developer Type	No. of Participants
Native Mobile Application Developer	**23**
Hybrid Mobile Application Developer	**7**
Mobile Web Application Developer	**4**

Which mobile platforms do you use to develop mobile applications (Check all that apply):

Native Mobile Application	Mobile Web Application	Hybrid Mobile Application
a. iOS (iPhone/iPad/iPod) (13 participants)	a. iOS (iPhone/iPad/iPod) (2 participants)	a. iOS (iPhone/iPad/iPod) (3 participants)
b. Android (18 participants)	b. Android (4 participants)	b. Android (7 participants)
c. Blackberry	c. Blackberry	c. Blackberry
d. Windows Mobile/Phone/8 (3 participants)	d. Windows Mobile/Phone/8 (1 participant)	d. Windows Mobile/Phone/8 (2 participants)
e. Other:	e. Other:	e. Other:

Which of the following apply to you as a mobile application developer?

Native Application Developer	Web Application Developer	Hybrid Application Developer
a. Freelance developer (5 participants)	a. Freelance developer (1 participant)	a. Freelance developer (4 participants)
b. Working in a company (12 participants)	b. Working in a company (1 participant)	b. Working in a company (1 participant)
c. Both of the above (6 participants)	c. Both of the above (2 participants)	c. Both of the above (2 participants)
d. Other:	d. Other:	d. Other:

TABLE 15. ***Continued.***

If you are employed in a company, how big is the mobile application developer team (including developers for different platforms):

Native Application Developer	Web Application Developer	Hybrid Application Developer
Only me (4 participants)	Only me (1 participant)	Only me (2 participants)
2-5 team members (9 participants)	2-5 team members (1 participant)	2-5 team members (2 participants)
6-10 team members (8 participant)	6-10 team members (2 participant)	6-10 team members (2 participant)
Other: More than 10 team members (2 participants)	Other:	Other: More than 10 team members (1 participant)

How many mobile applications have you developed so far (in each type/category of mobile applications):

Native Mobile Application	Mobile Web Application	Hybrid Mobile Application
Less than 10 apps (12 participant)	Less than 10 apps (2 participants)	Less than 10 apps (5 participants)
10-20 apps (3 participants)	10-20 apps (1 participant)	10-20 apps
More than 20 apps (8 participants)	More than 20 apps (1 participant)	More than 20 apps (2 participants)

Section 3: Mobile Application Development Challenges

The objective of this section is to identify the challenges of mobile application development (native, web and hybrid)? Please **tick** the appropriate box based on your experience of mobile application development.

Challenges	Strongly Agree	Agree	Disagree	Strongly Disagree	Not Sure
Fragmentation	☐	☐	☐	☐	☐
Testing	☐	☐	☐	☐	☐
User Experience	☐	☐	☐	☐	☐
Reuse of Code	☐	☐	☐	☐	☐
Compatibility	☐	☐	☐	☐	☐
Lack of Tools Support	☐	☐	☐	☐	☐
Lack of Expertise	☐	☐	☐	☐	☐
Change Management	☐	☐	☐	☐	☐
Security	☐	☐	☐	☐	☐
Other ☐ Yes ☐ No *If Yes, Please specify*:	☐	☐	☐	☐	☐

A comparison of the challenges (native, web and hybrid) identified in the literature indicates that there are slightly more differences than similarities between the challenges. On the other hand, the challenges (native, web and hybrid) identified in interviews indicates that there are more similarities than differences between the challenges. Our results show a weak negative correlation between the ranks obtained from the SLR and the interviews based empirical study. We also

found from our t-test that there is no significant difference between the findings of SLR and interviews.

Our study aims to provide mobile application developers, with a comprehensive set of challenges which will assist them in development of mobile applications (native, web and hybrid). Identifying these challenges will help industries to be ready for efficient mobile application development and facilitate them in the successful completion of mobile application development projects. We recommend that practitioners should give more attention to the frequently mentioned challenges identified in academia and industry. If mobile application development organizations are keen to know different challenges faced by native, web or hybrid application development organizations, then they should take into consideration the challenges identified in TABLE 5 and TABLE 7 respectively. In future, more empirical studies are needed to revise the existing studies with more diverse practitioners.

APPENDIX A
List of selected primary studies in SLR

See Table 14.

APPENDIX B
Interviews Questionnaire

See Table 15.

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