Crowdsourcing Requirements Engineering: A Taxonomy-based Review

Ghadah Alamer[1], Sultan Alyahya[2], Hmood Al-Dossari[3]
Information Systems Department-College of Computer and Information Sciences, King Saud University[1, 2, 3]
Information Systems Department-College of Computer and Information Sciences,
Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia[1]

***Abstract*—Interesting insights have been found by the research community indicating that early user involvement in Requirements Engineering (RE) has a considerable association with higher requirements quality, software project success and as well boosting user loyalty. In addition, traditional RE approaches confront scalability issues and would be time consuming and expensive to be applied with contemporary applications that can be surrounded by a large crowd. Therefore, recent attention has been shed on leveraging the principle of Crowdsourcing (CS) in requirements engineering. Engaging the crowd in RE activities has been researched by several studies. Hence, we synthesize and review the literature of the knowledge domain Crowdsourcing Requirements Engineering using a proposed taxonomy of the area. A total of 52 studies were selected for review in this paper. The review aims to provide the potential directions in the area and pave the way for other researchers to understand it and find possible gaps.**

***Keywords*—Crowdsourcing requirements engineering; crowdsourcing; CrowdRE; crowd**

I. Introduction

Today's software applications can be mobile, cloud and social which operate in crowd-based settings having a massive crowd of distributed users [1]. This shift in the nature of applications have stressed the need in extending user involvement during RE activities [2] [3]. Furthermore, to achieve global user acceptance and satisfaction, a software application should meet the needs and desires of the large base of users [4]. Due to that, incorporating the interested crowd in the early phases of a software application, specifically RE, is crucial. The broad concept that advocates the involvement of the crowd in RE tasks is CrowdRE.

Crowd-based Requirements Engineering (CrowdRE) is a recent concept introduced by Groen et al. [1] for all semi-automated or automated RE tasks involving the crowd. One of the potential areas for employing crowdsourcing is in RE where it has gained attention [2] [1] [5] [6]. The broad concept CrowdRE can involve crowdsourcing, but crowdsourcing doesn't involve CrowdRE [7].

It is worth mentioning that there are some differences between CrowdRE and Crowdsourcing Requirements Engineering. Crowdsourcing delegates a piece of work to the crowd to solve it [7], where crowd members are actively engaged. On the other hand, in CrowdRE, the crowd can be involved passively, where the approach harnesses the available data from the crowd. Moreover, in CrowdRE the crowd are informants, where in crowdsourcing they are considered as problem solvers [8].

Fig. 1 shows a generic and simplified classification of the area CrowdRE. As shown in the figure, in addition to crowdsourcing, feedback analysis is concerned about analyzing users' feedback about software in channels such as app stores, social media and product forum using text mining techniques to elicit users' requirements. Where usage and context mining enable monitoring software usage and context at runtime to derive users' requirements [9]. These two approaches are mostly considered as passive involvement of the crowd.

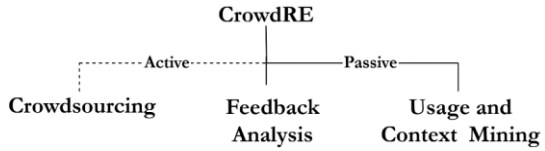

Fig. 1. General areas of CrowdRE [8] [9].

This review mainly covers studies that have utilized crowdsourcing for any of the RE tasks, where the crowd is actively involved in the crowdsourcing RE initiative. Moreover, we have suggested taxonomy of the area which we have observed after analyzing the selected studies, and reviewed the studies according to it. The taxonomy represents the main research directions in the area that can inspire interested researchers in finding potential gaps which are: crowd selection, crowd motivation, RE crowdsourcing platform, crowdsourcing task design and crowdsourced requirements. At the end of this review paper, we discuss some insights and provide some recommendations.

The reminder of this paper is organized in four sections: Section II which presents the research foci of the area Crowdsourcing RE. The section starts by showing the search and retrieval strategy for selecting studies and introduces the proposed taxonomy of the area. The studies are then reviewed according to the taxonomy. Section III discusses the overall insights that have been found and gives some suggestions. Finally, Section IV concludes this review paper.

II. Crowdsourcing Requirements Engineering: Research Foci

A comprehensive review of the main research foci of the broad area Crowdsourcing Requirements Engineering is presented. In addition, taxonomy of the area is proposed to provide the reader with an insight into the main directions of

the area that studies usually fall under. Each direction of the area is reviewed, and prior to that the undertaken search and retrieval strategy for selecting papers in the area is illustrated.

A. Serach and Retrieval Strategy

A selected number of keywords that mostly represent the area are used in searching for papers. The keywords are: [Crowdsourcing Requirements Engineering], [CrowdRE], [Crowdsourcing AND Requirements Engineering], [Crowd-Based Requirements Engineering]. Five main libraries were considered for searching papers which are: IEEE, ACM, SienceDirect, Springer and Scopus. In addition, the presented review covers published research anytime until 2023. Besides, we looked up papers published by some active researchers in the area and as well in the International Requirements Engineering Conference (RE) to find any related papers to be included in this review.

The review includes papers that apply the principle of crowdsourcing with any of the RE activities. Papers that fall under the area Crowdsourcing Requirements Engineering, which consider active involvement of the crowd during one or more of RE activities, are included. Papers that do not present a practical solution or review papers of the area are excluded.

Furthermore, papers that are cited by one of the selected papers and that appear to be related to the area Crowdsourcing RE are included. Fig. 2 is an illustration of the search and retrieval strategy that is followed to focus on Crowdsourcing Requirements Engineering studies. CrowdRE related papers are inspected to filter only papers that utilized crowdsourcing where the crowd is actively involved. Eventually, a total of 52 papers were selected for analysis and review.

After reviewing the current landscape of existing research in the area Crowdsourcing Requirements Engineering, it was noticed that research has mainly focused on addressing different aspects which can be considered as active research directions in the area. In Fig. 3, a taxonomy is illustrated of the Crowdsourcing Requirements Engineering literature. This taxonomy was set based on the main crowdsourcing elements presented by Hosseini et al. [10]. They have defined four pillars of crowdsourcing which are the crowd, crowdsourcer, crowdsourcing platform and crowdsourced task. Therefore, we present a taxonomy having four main aspects which are: the crowd, RE crowdsourcing platform, crowdsourcing task design and additionally crowdsourced requirements were added as a fourth aspect which particularly pertains to crowdsourcing RE. Each aspect of the taxonomy is reviewed and discussed in the next sections.

B. Crowd Selection for Crowdsourcing RE

From reviewing the selected studies, it was evident that a number have focused on proposing appraoches for selecting an appropriate subset of the crowd for crowdsourcing RE. A group of these studies have utilized social network analysis to select a crowd which are [11] [12] [13] [14] [15]. Lim et al. has designed StakeNet [11] which is a method for identifying and prioritizing a crowd of stakeholders in large software projects. The stakeholders are identified and prioritized by considering their level of influence they possess on a software project and their roles. Diverse social network measures are utilized to analyze the relations between the stakeholders in a social network. The network of stakeholders' crowd is built using snowballing technique where stakeholders recommend other stakeholders until a network of well-connected stakeholders is produced. Moreover, rather than relying on experts to ask stakeholders to suggest others, Lim et al. [12] has automated the process by developing StakeSource tool. The tool minimizes the workload on experts by crowdsourcing the task of stakeholder analysis to include the crowd of stakeholders in that task. In addition, StakeSource is improved by presenting a web-based tool called StakeSource2.0 [13]. StakeSource2.0 extends the work to not only consider stakeholders identification and prioritization, but as well elicits their requirements. To conduct this, the tool uses crowdsourcing, social network analysis and collaborative filtering.

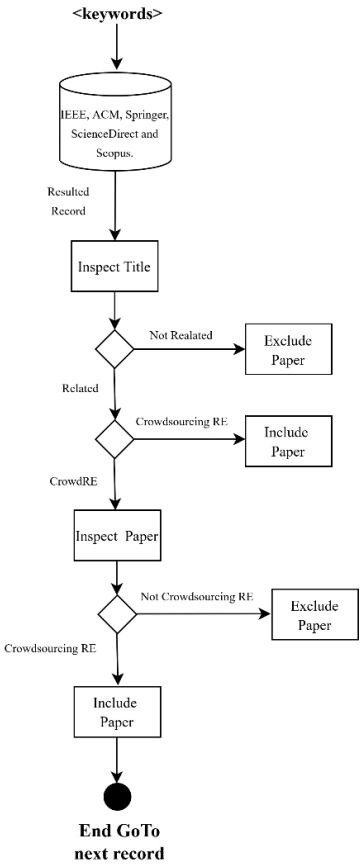

Fig. 2. Search and retrieval strategy.

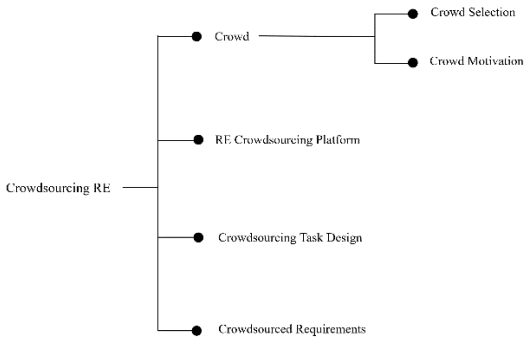

Fig. 3. Taxonomy of the area Crowdsourcing RE.

Moreover, StakeSource2.0 has been used in StakeRare [14] a method proposed by Lim et al. which identifies and prioritizes thousands of stakeholders for large-scale software projects and elicit their requirements. StakeRare was assessed on an extensive project consisting of a crowd of 30,000 stakeholders, and has shown to accurately predict the stakeholders' desires by producing a more complete list of prioritized requirements from the crowd of stakeholders. An in-group bias limitation was highlighted in the former studies by Mughal et al. [15]. This limitation is defined as when stakeholders prefer to recommend ones whom they have a good relationship with. This biasedness can lead to less accurate identification and prioritization of the crowd of stakeholders, which eventually impacts the process of requirements elicitation.

Rather than relying on the relations between the crowd members and the level of impact they have on software project such as what has been done by the previously discussed studies, other studies have considered the crowd's domain knowledge to select and identify a suitable crowd. A framework proposed by Wang et al. [16] aims to select suitable participants for outsourcing requirements elicitation tasks. The farmwork utilizes spatiotemporal features of the crowd to infer their domain knowledge. The authors observe that people who gather in the same spatiotemporal space could possess similar domain knowledge. For instance, to develop a football application, the best crowds to participate in requirements elicitation are football fans whom can be found clustering in a football match at a certain time and space. Furthermore, a study presented by Srivastava and Sharma [4] have focused on crowd with knowledge in ERP selected from LinkedIn social network. The crowd is selected to participate in crowdsourcing requirements elicitation for a software application called MyERP. They have used a crawling web-based solution to find crowd members who have listed ERP in their LinkedIn profiles as one of the expertise they possess. In addition, another study by Lim et al. [17] which uses LinkedIn as a platform from where the crowd is selected. They have proposed a systematic approach to find stakeholders interested in B2B software in a targeted company. The approach is a step-by-step strategy that assists in finding hidden B2B software stakeholders by searching LinkedIn social network. The targeted stakeholders are found by a set of intermediates called advisors that help connect with the stakeholders and elicit their requirements for a B2B software. In addition, a nichesourcing method was proposed by Condori-Fernandez et al. [18] for analyzing sustainability requirements and the dependencies between them. The method consists of multiple stages, where an early stage is selecting a crowd experienced in a domain knowledge that fits the software having its requirements crowdsourced. The authors recommend using social network sites such as Twitter and LinkedIn to find a potential crowd of experts to contribute in crowdsourcing sustainably requirements and finding the relationships and dependencies among them.

Some studies have based the selection process on the crowd's domain of interest. A method proposed by Lim et al. [19] utilized a bot tool which operates on Twitter social network. The automated tool is called PseudoGravity and it aims to identify a targeted interested crowd by generating content that is especially tailored for them. The interested crowd is then engaged in participating in crowdsourcing requirement elicitation tasks. Moreover, Kolpondinos and Glinz [20] have proposed an approach to select an interested crowd that is beyond the bounders of an organization. They have harnessed several online channels as a source to find a crowd interested in the SmaWoMo system. Their approach employs persona-based advertisements which are based on player-types similar to personality traits to determine the personas. The targeted crowd is then invited to engage collaboratively in the requirement elicitation and prioritization process for that system.

A study conducted by Alvertis et al. [21] have introduced a persona-based approach that can be used to select a suitable subset of the crowd to participate in the process of requirements elicitation. Their approach consists of a persona builder tool that enables software teams to construct, reuse, and as well share personas. A persona can be created by identifying a set of required characteristics. This approach assists in targeting suitable prospective software users. The crowd that fits these determined personas can be selected to get involved in crowdsourcing requirements engineering. In addition, Guzman et al. [22] have built a stakeholder identification model using machine learning techniques. Their model can identify the stakeholders from tweets, where they are either classified as technical, non-technical or general public stakeholders. They have built their model using tweets about 30 popular mobile and desktop applications.

C. Crowd Motivation for Crowdsourcing RE

In the literature of crowdsourcing RE, some studies have focused on how to motivate the crowd to participate in a crowdsourcing initiative. The authors in [2] [20] [23] [24] [25] [26] [27] [28] [29] advocated the use of Gamification as an incentive design to increase crowd motivation when crowdsourcing RE tasks. Gamification is the idea of using game elements such as points, levels, badges and leader boards in non-game context to motivate users [36]. Fernandes et al. [24] have proposed iThink, a gamified collaborative tool for requirements elicitation which uses the "Six Thinking Hats" technique. Moreover, stakeholders are rewarded for suggesting new requirements or discussing existing ones. This study is considered as one of the early attempts revealing that gamification has potentials in RE activities [23].

Snijders et al. [23] have extended participation by involving a crowd of stakeholders. The authors have proposed REfine, a gamified crowdsourcing platform for requirements elicitation and refinement which is an essential component of the (Crowd-Centric Requirements Engineering) CCRE method [2] [23] [25]. REfine is designed to involve crowd of stakeholders in RE. Through REfine users are able to suggest needs, comment on them, branch them, vote for them, and are rewarded accordingly.

Furthermore, Martina et al. [26] have developed a concept to motivate the vast number of unknown stakeholders outside organizational reach to contribute in requirements elicitation using gamification mechanisms. The authors argue that all implemented game-based platforms for requirements elicitation (e.g. iThink [24] and REfine [23]) have considered crowd of

stakeholders who are within organizational reach. Besides, they have overlooked the evolution of stakeholders' motivation throughout the elicitation process; hence, the authors have focused on addressing this gap.

Similar to [26], another study [27] has focused its investigation on motivating stakeholders outside organizational reach and specifically during requirements prioritization. Garuso (Game-Based Requirements Elicitation) platform which incorporates social media with gamification was developed to explore the effect of gamification algorithms that control the points and levels game elements on stakeholders' participation. Kolpondinos and Glinz [20] have presented the GARUSO approach which was an expansion of the studies [26] and [27]. The authors have presented a detailed description of the GARUSO architecture, which is a gamified social media platform that enables the crowd of stakeholders outside the organizational reach to collaborate in eliciting and prioritizing requirements. Besides, Gupta [28] have used gamification for requirements elicitation and prioritization, The crowd are asked to express their requirements using customer journey format which shows the step-by-step journey of a customer in performing a task (e.g. payment task).

The above discussed studies have used gamification mechanism for crowd motivation. Nevertheless, some studies have designed rewarding systems as part of their studies to keep the crowd motivated such as [4] [30] [31]. Srivastava and Sharma [4] have proposed a crowdsourcing approach for requirements elicitation for MyERP application. To maintain crowd motivation, they have used certain performance measures. Two main indicative measures were utilized, which are members who contribute more requirements and who have more responses posted on their contributed requirements, are given a reward. In addition, Seyff et al. [31] plan to add a personalized rewarding mechanism to encourage the crowd to participate in their platform and maintain their involvement in negotiating and analyzing the requirements with respect to sustainability. Nascimento et al. [30] have defined three reward methods for their proposed framework which are reward and career, financial compensation and recognition. For which a selection of a method is based on the scope of the project and the type of participating crowd.

Schneider and Bertolli [32] state that having a software described in text format may not be encouraging for the crowd to share their opinions and feedback about that software and might even repel them from contributing. Therefore, they suggest a new approach in motivating the crowd for RE, which is using videos. They have proposed four types of videos and illustrated how they can be created and make them engaging for CrowdRE. In addition, in [33] the authors have designed a gradual approach for eliciting and gathering requirements from a crowd, where requirements are built gradually from multiple micro-crowds (MCs). In each MC, the people are familiar with each other. This approach can perform better in motivating the crowd than when starting with a large crowd, where this has been seen to fall under the motivation linked to loving the community. Another study by [34] has applied the MC approach, however, rather the applying it on users as in the previous study, it was applied on developers.

D. RE Crowdsourcing Platform

The literature shows that there are several crowdsourcing platforms that are especially designed for crowdsourcing RE tasks. CrowdREquire [35], REfine [23], CRUISE [5], UCFrame [36], Requirements Bazaar [37], GARUSO [20], CREeLS [38], CREUS [39], SCOUT [40], Liquid RE [41], KMar-Crowd [29], Srivastava and Sharma's platform [4], Seyff et al.'s platform [31], Nagel et al, prototype [42], smartFEEDBACK [43], CrowdConfigRE [44] and Menkveld et al.'s platform [45] are all crowdsourcing platforms for RE.

CrowdREquire proposed by Adepetu et al. [35] aims to focus on gathering requirements from the available diverse talent in the crowd which is considered as a complex task. The platform utilizes a contest model and adopts an agile approach for requirements development. Another platform proposed in [37] which involves the crowd in almost all RE activities. The authors have designed a platform for social requirements engineering named Requirements Bazaar. It supports collaborative requirements elicitation, prioritization, negotiation and realization. Besides, it has a co-creation workflow involving four stages: idea generation, idea selection, idea realization and idea release.

Sharma and Sureka [5] have designed a platform for crowdsourcing RE activities called CRUISE. CRUISE aims to employ the crowd in gathering, analyzing, validating, prioritizing and negotiating requirements. In addition, Hu et al. have proposed USFrame [36], a use case-based framework for collaborative requirements acquisition in crowd-centric context to assist the crowd in expressing their requirements without the help of an analyst. The platform has implemented critical mechanisms such as rule hints for guiding the crowd of users in use case documentation, built in abstract types, use case synthesis, quality measurements and visualization diagrams.

Munante et al. have proposed CrowdConfigRE [44], a platform for crowdsourcing re-configuration requirements that focuses on adaptive systems to elicit their re-configuration requirements. First, known crowd, in other words domain experts, generates personas and configuration profiles for adaptive software. Then, an unknown crowd of potential users are used to refine and validate the information elicited; hence, accurately defining the re-configuration requirements. Furthermore, Seyff et al. [31] proposed a platform that can engage a crowd, users and domain experts, in negotiating and eliciting requirements and their impact on sustainability. The platform consists of three primary parts which are CrowdFeed component that enables the crowd to share their feedback about a software product, ReSuS component to classify and cluster the feedback and ReSIntegrator component that showcases the impact on sustainability using visualization techniques.

REfine [23] and GARUSO [20] are gamified collaborative crowdsourcing platforms for RE activities. REfine platform engages a crowd of users, developers or requirements analysts in the process of eliciting and refining software requirements. Similarly, GARUSO platform allows the crowd to collaboratively engage in requirements elicitation and prioritization tasks. Additionally, Menkveld et al. [45] have developed a RE crowdsourcing platform to help the crowd in writing their software requirements and features in the form of

user stories (US) for a sports tournaments management software. It enables the crowd to submit their US by entering four inputs which are: the role of the crowd member requesting the feature, the goal of the feature, the benefit of the feature and the category of the feature. Besides, CREUS method [39] has used user stories as an approach to express ideas elicited from the crowd. The method consists of four phases which are: preparation, idea generation, refinement, and execution and supports three main roles: core team, crowd member and focus group member. Core team oversees and coordinates the crowd, the crowd member contributes ideas, and focus group member is a crowd member who participates in discussing the development of the crowdsourced ideas. Another similar platform is Kmar-Crowd [29] which is designed for crowdsourcing requirements elicitation in the form of user stories. The platform involves the crowd in idea generation and refinement to generate ideas and vote and comment on available ideas. In addition, a study conducted by Köse and Aydemir [40] have proposed SCOUT a web-based tool which supports the completeness of user stories generated by a crowd of stakeholders in a collaborative environment. SCOUT NLP-based tool guides the crowd during the process of generating user stories. It uses NLP to construct a knowledge graph from user stories; hence, heuristics are applied on the knowledge graph to produce suitable suggestions to the crowd of stakeholders.

A platform proposed by Rizk et al. [38] called CREeLS is a crowdsourcing platform to crowdsource requirements elicitation tasks for e-learning systems (eLSs). The proposed platform consists of feedback channels to comment and review the eLS, social collaboration, text mining tools to analyze and mine the crowd requirements that are written in the form of comments and in discussion forums. Moreover, a crowdsourcing platform was proposed by Srivastava and Sharma [4] for crowdsourcing requirements elicitation for ERP applications. Their proposed platform has addressed several challenges concerning identifying the appropriate crowd, keeping them engaged, identifying appropriate tasks, recognizing malicious crowd members and resolving conflicts among requirements and prioritizing them. Additionally, a tool called smartFEEDBACK [43] was developed to apply crowdsourcing RE to gather the needs of older adults. The tool was designed to support both explicit (e.g. answer questions) and implicit feedback (e.g. analyze interactions).

Nagel et al. [42] designed a prototype for an interactive video player which incorporates three main features which are emoji markers, comments and hyper-markers. These features shall enable the crowd of stakeholders to understand and share their understanding and requirements about a software project and assist in resolving any conflicts. Moreover, a study by Johann and Maalej have proposed an envision of a Liquid RE platform [41]. The platform applies Liquid Democracy and e-Democracy concepts in RE to mitigate the challenges of mass participation in RE related to scalability, motivation, conflicts, representativeness, subjectiveness and misuse. Some of the main Liquid Democracy and e-Democracy concepts to be applied in the platform are structured collaborative decision making, delegated voting and quorums.

E. RE Crowdsourcing Task Design

Indeed, some studies have focused on the task design for crowdsourcing RE, where they presented a method that could simplify and decompose the crowdsourced task. Mostly, these studies utilized available crowdsourcing platforms such as the general-purpose crowdsourcing platforms Amazon Mechanical Turk (MTurk), Figure Eight and Zooniverse and focus on task design.

The crowd-based requirements annotation methods Kyoryoku [46] and CRAFT [47] harness the power of the crowd in eliciting and classifying requirements from users' reviews. The methods split complex tasks into simpler micro-tasks. Using CRAFT [47], crowd members from Figure Eight accomplished a task by navigating through three major phases. A crowd member first selects a category from predefined categories (e.g. functional requirement, bug report) for a review or adds a new category. Second, selects a sub-category and third rates the importance of the review and provides comments. Furthermore, Kyoryoku [46] method, inspired by CRAFT, proposed a three phase method for accomplishing the task of extracting requirements from users' reviews. First a crowd member filters a review into helpful or useless, second fragments of the helpful reviews are further classified to being helpful or useless, and third helpful fragments are classified into five categories (e.g. feature request, stability, quality). Similarly, CrowdIntent [48], a crowdsourcing workflow proposed for annotating intentions (desires and needs) hidden in discussions into a set of categories. It has decomposed the content of the task (a discussion) into messages then into sentences using sentence splitter tools to design the task in an understandable way for annotation.

Furthermore, Murukannaiah et al. [49] have proposed a sequential task design for crowdsourcing RE through MTurk which can stimulate creativity. The design was based on the notion that when workers are exposed to others' ideas, this act can lead to cognitive stimulation. There are two phases, where in the first phase the crowd workers review the ideas generated by other workers and generate new ones. In the second phase, the other part of the crowd rates the produced ideas in the first phase. In addition, an idea selection strategy based on workers' personalities and creativity was proposed to select a set of ideas from a stage to be exposed to workers in the following stage. Moreover, Breaux and Schaub [50] introduced a task decomposition workflow for crowdsourcing the manual extraction of privacy requirements task from text documents which involve privacy policies. The task includes multiple microtasks which enables untrained crowd members to apply sentence and phrase level coding of the privacy policies. The workflow is performed using manual methods, and as well NLP techniques to automate some parts of the workflow.

Alongside Breaux and Schaub's study [50], another was conducted by Guo et al. [51] that have proposed Çorba which focuses on the task design for crowdsourcing RE. Çorba is a crowdsourcing design that guides the crowd in extracting security and privacy requirements from regulations and breach textual reports by breaking the task into smaller tasks. The proposed task design was conducted on MTurk crowdsourcing platform. In addition, Rosser et al. [52] used Zooniverse for crowdsourcing phishing cues labeling which is a crucial RE

phase for anti-phishing training tools. Zooniverse markup interface was used to design the crowdsourcing task. Participants were shown screenshots and were asked to identify its trustworthiness, if the content is malicious, they are asked to mark the areas in the image indicating phishing and then label it using pre-defined labels. Furthermore, another study has used a simple mean for crowdsourcing such as using questionnaires as done by Vidal et al. [53], where they have crowdsourced the task of requirements validation for a pet management mobile app. Their questionnaires were designed using questions with Likert-scale, binary or numeric responses to validate the requirements.

F. Crowdsourced Requirements

In addition to all previously discussed studies, some have mainly focused on how to handle the crowdsourced requirements; hence, they are more concerned about the stage after gathering the requirements. The papers [54] and [55] have proposed a genetic algorithm-based approach in which the elicited requirements from the crowd are aggregated. They have used activity diagrams as a structured requirements description language in order to facilitate automated merging of requirements. Their proposed genetic algorithm aims to merge the collected activity diagrams from the crowd, and produce a synthetic activity diagram which acts as a crowd consensus on a requirement. Moreover, Taj et al. [56] have presented a model that classifies requirements gathered through crowdsourcing into functional and non-functional requirements. An open call was initiated to ask crowd members to participate in submitting requirements for a software to be developed. The model used the machine learning algorithms naïve bayes and decision tree to build the model and has proved to achieve effective results.

Furthermore, StakeSource2.0 [13] and StakeRare [14] use social networks and collaborative filtering to identify and prioritize requirements from a large crowd of stakeholders which are asked to suggest and rate requirements. Collaborative filtering predicts a stakeholder's preferences and recommends unrated requirements to a stakeholder that might be of interest to him; hence, the stakeholder rates this recommended list of requirements. Using these ratings and the stakeholder's level of impact on a project, the requirements are prioritized.

Indeed, having large number of requirements as a part of the software project with no value to users is an issue. To rectify such problem, Nascimento et al. [30] have proposed a framework which leverages Kano's model to classify and evaluate crowdsourced requirements. The proposed framework aims to identify and prioritize requirements based on their importance to the customers and include them for implementation. Similarly, Niu et al. [57] have proposed an approach where they have employed semantic discrimination lexicon, Kano model and entropy technique to evaluate the importance of already crowdsourced requirements. Furthermore, Hassan et al. [58] proposed an approach which uses text mining and morphological matrix for analyzing the large number of ideas generated by the crowd to extract innovative software requirements. Mead et al. [59] on the other side have proposed an approach where they utilized crowdsourcing to construct Personae Non Gratae (PnGs)-based threat models that could be considered as input for early phases of requirements process, and as well help in specifying mitigating requirements. For the aim of reaching higher coverage of threats, reducing redundancies and developing meaningful PnGs, in their approach they have introduced a merging strategy where they used machine learning and information retrieval techniques to merge crowd's PnGs.

III. DISCUSSION

After reviewing crowdsourcing requirements engineering body of knowledge, the reviewed studies are synthesized in Table I where each study is categorized under one or more dimensions that it contributes to according to the suggested taxonomy illustrated in Fig. 3. Apparently, the largest number of studies contributed to the Crowd dimension and the RE Crowdsourcing Platform dimension. Furthermore, regarding the remining two dimensions crowdsourced task design and crowdsourced requirements, the number of studies addresses a gap related to these dimensions are quite low.

TABLE I. STUDIES ORGANIZED UNDER THE DIRECTIONS OF THE AREA CROWDSOURCING RE

Dimensions		Number of Studies	Ref.
Crowd	Crowd Selection	13	[20] [4] [16] [17] [12] [14] [15] [13] [11] [21] [19] [22] [18]
	Crowd Motivation	15	[2] [20] [4] [33] [23] [30] [32] [24] [25] [26] [27] [28] [29] [31] [34]
RE Crowdsourcing Platform		17	[23] [5] [36] [37] [20] [38] [41] [4] [31] [35] [44] [45] [29] [39] [40] [42] [43]
Crowdsourcing Task Design		8	[46] [49] [51] [50] [47] [48] [52] [53]
Crowdsourced Requirements		9	[13] [14] [30] [54] [56] [58] [59] [55] [57]

We envision that there are areas for improvements in this field, where studies can work on designing effective approaches for crowd selection that can infer the knowledge of the crowd and make use of it in various activities of requirements engineering. Moreover, motivating the crowd is a factor of paramount importance especially when it comes to crowdsourcing. Therefore, we recommend working on strategies that can incentivize the crowd to participate. For the RE crowdsourcing platforms, there are several endeavors in this dimension. Nonetheless, since RE tasks are considered as complex tasks, designing a platform that does not just provide a medium for the crowd but as well facilitates the accomplishment of the crowdsourced RE tasks by incorporating intelligent features in the platform, is another factor to consider when researching this dimension.

Furthermore, the task design aspect has large opportunities for contributions. It is recommended to design a RE crowdsourced task in a way that can be employed in any crowdsourcing platform. The last dimension which is focused on the crowdsourced requirements have few studies contributing to it. To benefit from the crowdsourced requirements, we suggest proposing methods to aggregate the large number of contributed requirements and synthesize them.

This can assist crowdsourcing requesters in understanding and viewing them.

Employing crowdsourcing in requirement engineering might present some challenges that need some attention. The quality of the crowdsourced requirements reducing redundancies and increasing diversity when crowdsourcing requirements and as well coordinating the work on RE tasks among crowd members are all important aspects that can be researched.

IV. Conclusion

Crowdsourcing requirement engineering is a new approach for RE which fits the modern software paradigms. Hence, we have presented a thorough review of the area and proposed a taxonomy that can help researchers find their way in the area. The review shows that there are some aspects of the area that can be contributed to and enhanced. In addition, for future work we plan to conduct some research work that could address some gaps identified in the area.

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