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RESEARCH ARTICLE

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Work-from-home impacts on software project: A global study on software development practices and stakeholder perceptions

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Context: The COVID-19 pandemic has had a disruptive impact on how people work and collaborate across all global economic sectors, including software business. While remote working is not new for software engineers, forced WFH situations come with both limitations and opportunities. As the 'new normal' for working might be based on the current state of Work-from-home (WFH), it is useful to understand what has happened and learn from that.
Objective: This study aims to gain insights into how their WFH arrangement impacts project management and software engineering. We are also interested in exploring these impacts in different contexts, such as startups and established companies.
Method: We conducted a global-scale, cross-sectional survey during the spring and summer 2021. Our results are based on quantitative and qualitative analysis of 297 valid responses.
Results: We characterize the profile of WFH in both spatial and temporal aspects, together with a set of common collaborative tools and coordination and control mechanisms. We revealed some areas of project management that are relatively more challenging during WFH situations, such as coordination, communication and project planning. We also revealed a mixed picture of the perceived impact of WFH on different software engineering activities.
Conclusion: WFH is a situational phenomenon which can have both negative and positive impact on software teams. For practitioners, we suggest a unified approach to consider the context of WFH, collaborative tools, associated coordination and control approaches and a process that resolve those aspects that are sensitive to physical interaction.

KEYWORDS
COVID-19, empirical study, project management, software engineering, work-from-home

Abbreviations: GSD, global software development; MVP, minimum viable product; PO, primary observations; RQ, research question; SE, software engineering; UX, user experience; WFH, Work-from-Home.

For affiliations refer to page 26.

1 INTRODUCTION

Work-from-home (WFH) is increasingly being recognized as a popular work arrangement due to its many potential benefits for both companies and employees (e.g., increasing job satisfaction and retention of employees).[1–3] WFH has been known in many different terms, such as remote work,[4,5] virtual teams,[6,7] and teleworking.[8–10] Remote work is not new, and it is not uncommon to have software development undertaken in a multisite, multicultural, globally distributed setting.[11,12] However, with the recent COVID-19 pandemic, many companies were forced to adopt the WFH model, regardless of suitability to their business model, product nature, the current setting of teams and organizations.[13] As estimated recently, there might be close to 40% people working in the EU who began to telework full-time as a result of the pandemic.[14]

Many companies decided to switch to long-term remote work. In May 2020, Twitter's CEO at that time informed their staff that they could work from home forever*. Coinbase has become a 'remote-first' company, allowing most staff who want to work remotely to do so indefinitely. Dropbox too will let all employees work from home permanently† and Amazon has stated that employees whose positions allow them to work from home can do so two days a week‡. While teleworking is not new in many organizational settings, recent studies in the context of COVID-19 agree that significant changes to the workplace or way of working will occur in post-pandemic times.[15–17] Organizations might face various configurations of WFH, from a hybrid mode of office and online work to working from anywhere.[17]

Several research topics are useful for maintaining a safe and productive working environment in a WFH arrangement. Well-beingness, psychological safety and work-life balance have been quite well explored in a software industry context.[18–23] These studies conceptualize constructs, such as well-beingness, fear, stress, distractions, communication and happiness and relate them to individual performance on different software engineering activities.

In contrast, there are relatively less studies about WFH at a team level. Since software development is a collaborative effort, it is essential to investigate the impact of WFH settings on the different activities of the software development processes. It may be difficult for project managers to communicate via e-communication tools since they cannot substitute face-to-face interaction, especially in a complex setting. Project managers might also need to adopt new practices or mechanisms to trace and coordinate software development activities in different WFH settings.[24] The impact of new work arrangements on different software development activities, such as requirements engineering, coding, and testing, might be diverse due to the various need of physical communication and coordination.

This effect might be heightened in scale for software development teams in startup and small companies due to their vulnerability to macro environmental changes. Bai et al. found that WFH practices are critical for startup companies to maintain their operations.[25] To the best of our knowledge, no study about WFH has focused on software startups. Given the particular characteristics of this kind of company, such as their entrepreneurial characteristics, the relationship with the customers, small team size, lack of resources, and immature adoption of practices[26,27] changes induced by new work arrangement could have unique implications.

The first objective of this paper is to explore how professionals perceive the impact of WFH during COVID-19 on different software project management and software engineering activities. As part of this goal, we aim to highlight, from their perspective, which activities have been most impacted, both positively or negatively. The second objective of this paper is to compare the impact of the WFH situation on teams in software startups and established companies regarding different software development activities. Based on these objectives, the present study focuses on addressing the following research questions:

1. RQ1–How does the way of working in software teams change when WFH is adopted?
2. RQ2–How is project management impacted when WFH is adopted?
3. RQ3–How are software engineering activities impacted when WFH is adopted?
4. RQ4–Is there any difference between startups and established companies regarding the above impact?

The outcomes of the study are three-fold. Firstly, it provides a worldwide and diverse set of evidence on WFH practices in the software industry. Secondly, the study describes different practices to manage, communicate and coordinate in

*https://www.forbes.com/sites/danabrownlee/2020/05/18/twitter-square-announce-WFH-forever-optionwhat-are-the-risks/.

†https://www.businessinsider.com/what-spotify-twitter-goldman-sachs-said-about-long-term-remote-working-2021-3.

‡https://www.flexjobs.com/blog/post/companies-switching-remote-work-long-term/.

a WFH setting. Thirdly, the study is among the first to offer a worldwide survey on project management and software engineering with a comparative view between startups and established companies.

The next section captures the relevant literature on WFH in software engineering and software startups. Section 3 presents our research approach. Sections 4 and 5 present and discuss our results while Section 6 concludes the paper.

2 | RELATED WORK

This section briefly reviews existing work on the three key concepts: WFH, WFH in software engineering, and software startups. In the end, we present our conceptual framework to guide our analysis and findings.

2.1 | Work-from-home

Work-from-home (WFH) has been referred to using many different terms, such as teleworking, remote working, and virtual team working. WFH is not a new phenomenon. Studies on the phenomenon has dated back to the 1970s, when the motivation for WFH was thought to be to manage resource shortages, reduce daily commuting or to balance work and family duties.[6,10,28,29] WFH has been characterized as needing minimum physical requirements, individual control over work pace, defined deliverables, a need for concentration, and a relatively low need for communication.[4]

In general, WFH is often claimed to improve productivity[30,31] and teleworkers do consistently report increased perceived productivity.[32,33] WFH gives people more flexible working time providing better work-life balance, saves on the cost of maintaining a central working place and may give better job satisfaction. However, WFH is found to be associated with greater levels of both work pressure and work-life conflict[34] because work intrudes into developers' home lives through working unpaid overtime, thinking about working hours, exhaustion and sleeplessness.[35] It may be that many organisations lack appropriate plans, supportive policies, resources or management practices for practicing WFH.

2.2 | WFH and software industry

The software industry, a dynamic and ever-evolving sector, serves as the digital backbone of the modern world, driving innovation across various domains. Given the software industry's reputation for embracing innovative work methodologies, the introduction of remote work has had a substantial influence. However, it's important to note that the extent and nature of this impact can vary widely, largely depending on the specific organizational context. Bao et al. conducted a quantitative analysis based on a dataset of developers' daily activities from Baidu Inc.[23] The authors found that WFH had both positive and negative impacts on developer productivity in terms of different metrics, for example, the number of builds/commits/code reviews. Forsgren et al. studied open source projects in Github and showed that developer activity in terms of number of pushes, pull requests, code reviews and commented issues remained similar or slightly increased compared to the pre-pandemic year.[36]

Ralph et al. performed an extensive study of the pandemic impact on programming, including productivity in the early months of WFH.[20] They concluded that perceived productivity has declined (admitting a marginal effect size) as a result of negatively affected well-being and that organizations need to accept that expecting normal productivity under crisis circumstances is unrealistic. Ford et al. conducted a two-wave study on productivity in Microsoft.[15] Both surveys indicated that productivity increased among some participants and stayed the same or decreased among the others.

Russo et al. performed a two-wave longitudinal study with a diverse group of professionals, diving into the impact of over 50 psychological, social, situational, and physiological factors and their ability to predict the variance in well-being and productivity.[21] The study concluded with a few associations between the studied factors and perceived productivity. Oliveira et al. gathered data from two online surveys of Brazilian professionals.[37] The authors found that perceived productivity in WFH when comparing with the office times has increased. Another important finding made regarding the changes in perceived productivity during the pandemic was that the number of positively affected respondents grew from 40% in the first wave to 60% in the second wave.

Smite et al. studied 13 surveys in the literature finding that on average, perceived productivity had not changed significantly; there are developers who report being more productive and developers who are less productive when working from home.[16] Also, positive trends are found in longitudinal surveys, that is, developers' productivity in the later months of the pandemic show better results than those in the earlier months. Nolan et al. conducted a qualitative study on software engineering during the COVID-19 pandemic.[18] The authors showed that software companies would derive tangible benefits from supporting their employees during this uncertain time through ergonomic home offices, listening to their concerns, as well as encouraging breaks and hard stops to boost long term well-being and productivity. Machado et al. explored gendered experiences of software engineers during the COVID-19 crisis[38] and found that women face particular challenges during social isolation, as they were more likely to lack support with household and childcare responsibilities.

2.3 WFH in software startups

Software startups represent a unique and dynamic context within the software industry. Unlike established software companies, startups are typically newly formed ventures that are focused on developing innovative software products, services, or solutions. Berg et al. summarized a common definition on software startups as companies with an innovation focus, lack of resources, working under uncertainty and time–pressure, highly reactive and rapidly evolving.[26] Startups are found to be different from established companies in the strong presence of entrepreneurial personalities, behaviors, decision-making and leadership.[27,39,40]

Software startups, in particular, tend to excel at adaptability and flexibility[27] and we should expect them to demonstrate that in response to the COVID-19 crisis. Startups is known for their inherent agility and adaptability that allows them to pivot swiftly in response to evolving market dynamics, while larger, established firms often grapple with bureaucracy and legacy systems.[27,41] Moreover, their tech-savvy nature could allow them to seamlessly transition to virtual collaboration, ensuring business continuity. Software startups have been instrumental in adopting the digital tools and environment needed to facilitate remote work for companies across industries. Consequently, we have a good reason to believe that we can observe the special impact of project management and work practices in software startups that can benefit the software industry.

2.4 Conceptual framework

Collins et al. reviewed and discussed different roles of theory in empirical work, and one of them is to provide focus and organization to the study.[42] Maxwell refers to a conceptual framework as "an idea context of the study".[43] The conceptual framework should assist the researcher in refining goals, developing research questions, discerning methodological choices, identifying potential threats to validity, and demonstrating the relevance of the research. The primary source of the conceptual framework, from his perspective,[43] does not necessarily need to be an existing theory. Four primary sources are options from which to derive a conceptual framework: (1) knowledge based on experience, (2) existing theory, (3) exploratory research, and (4) 'thought experiments'.[42]

Figure 1 consists of three main conceptual blocks–distributed work arrangement due to the pandemic situation, perceived impact on project management, and perceived impact on software engineering.

Distributed work arrangement depends on the policy and setting of individual companies. There are three important aspects of a distributed working condition that have been explored in global software development (GSD) research,[11,44] namely the distribution profile,[45] the usage of tools,[46] and the coordination and control practices and mechanisms and approaches for control and management.[45] The configuration of an distributed team is usually seen from the combination of the extent that a team spreads over geographical locations and timezones.[45,47] Collaboration tools are essential in a virtual team. Various common tools that are reportedly common in global software development[46] should be revisited in the context of forced virtual collaboration. We also take input from control and coordination practices that are previously reported in global teams.[48–51]

Project management: Communication, collaboration and coordination, the major managerial activities in a software project, are expected to be significantly affected by the shift to new working conditions. GSD research has highlighted important managerial aspects in software projects that are under high uncertainty and fast-changing environments, including team and task awareness, mid-term to long-term planning and team culture.[52–54] Through one of our design meetings, we also considered team competence as a potential area of impact. Changing work arrangements might imply the needs of new roles or new competence in the team.

Software engineering: We decided to focus on basic software engineering roles and activities to achieve broad coverage in the survey. The selected areas also reflect the research interests of the authors. The seven activities areas are Requirement Engineering, Software Archicture, UX Design, Implementation, Quality Assurance and Software Process. These areas also match the occupation of the majority of survey respondents, as shown in Figure 2.

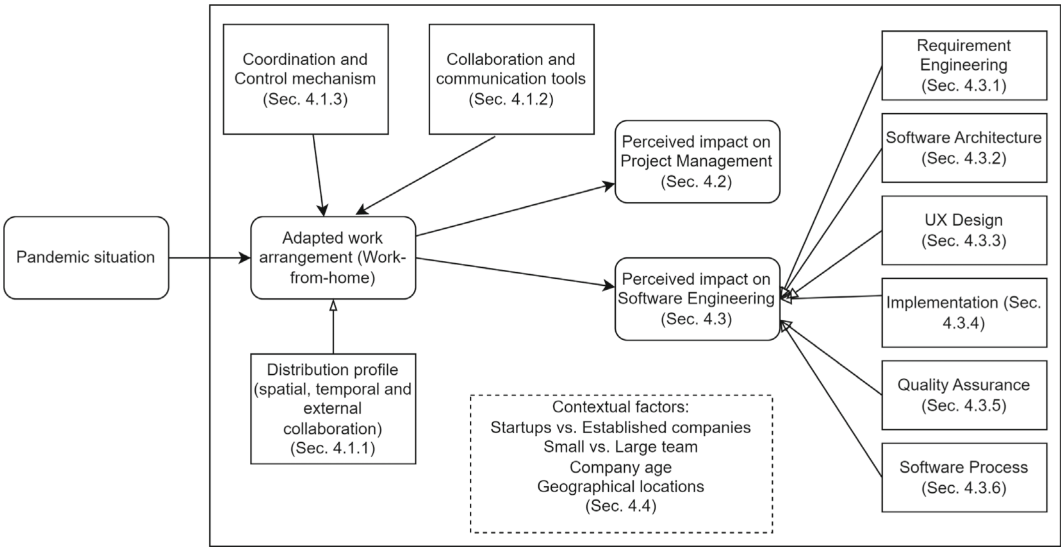

FIGURE 1 A conceptual framework.

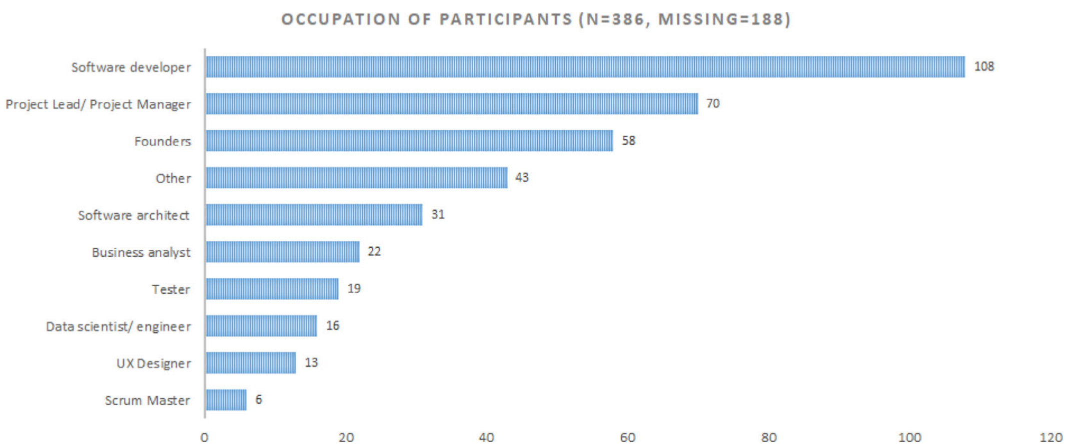

FIGURE 2 Occupational distribution among participants.

3 | METHODOLOGY

The original objective of the survey was to gain insights into how the way of working has changed into WFH and how it impacts software engineering, project management, innovation and resilience. This section presents our study design (Section 3.1), Instruments (Section 3.2), Sampling strategies (Section 3.3), Data collection (Section 3.4) and Data analysis (Section 3.5)

3.1 | Survey design

The survey is designed as a cross-sectional study with a mix of close-ended and open-ended question.[55] The survey design process started in October 2020 and ended in March 2021. The initial foundation for the studies was a set of few studies about COVID-19 and startups or software engineering. It is noted that at the time the study was designed, there are not many papers found in this topic. The literature was updated gradually during the analysis and report writing. The study design was influenced by a large group of researchers. Typically, a brainstorming section for study design involves between 15 to 25 researchers from Brazil, Norway, Italy, Finland, Sweden, UK, Portugal, Germany, Australia, Canada, China, and Vietnam. Many of these people are co-authors of this work. We conducted bi-monthly work sessions via video-conference,

TABLE 1 Major versions of the survey.

Ver.	Major activities	# meetings	Sample size	Tools
1	Testing and validating theoretical elements	5 meetings	5 internal participants	Paper based
2	Reducing the number of questions, adding opt-out options	3 meetings	25 pilot companies	Google form
3	Adding more open-text questions, removing one-person companies	2 meetings	5 internal participants	Lime survey
4	Revising questions, correcting inviting text, languages	2 meetings	574 responses	Lime survey

either for brainstorming or focus group to design the survey, discuss and work on the project. The result of this design process is three major versions of the survey (details on piloting and validating these versions are shown in Table 1).

The study's target population is software development teams worldwide who switched from working in an office to working from home because of COVID-19. Stakeholders who had been working remotely before the pandemic are also important, but this study is about the switch, and the questions are designed for people who switched from working on-site to WFH. The unit of analysis in this study is a software development team. We implemented several approaches to making sure each participant could validly represent their teams. In principle, the questionnaire was open to a wide range of software development stakeholders, from business analysts, designers, software developers, testers, Scrum masters to startup-specific roles, such as CEOs or CTOs.

3.2 | Instruments

The overall instrument used in this research constitutes in total 45 questions. The survey includes sections designed to (1) understand the current working conditions of the participants; (2) the contextual background of the participants, including the company and individual characteristics; (3) the perception of the participants about the impact of COVID-19 on software engineering activities in their team and companies; (4) the perception of the participants about the impact of COVID-19 on their companies' innovation and resilience; and (5) the perception of the participants about the impact of COVID-19 on perceived performance.

We used both yes-no questions, multiple-choice questions (application domains, digital tools, team size etc.), and five-point Likert scale multiple-choice questions. Some questions, for example, regarding digital tools participants are using, employed a free text option, for example, 'tool names' or 'other' so that the respondents can specify their choice better. We also use several open-text questions to get more details from the participants. In a Likert ordinal-scale question, we have five standard choices: (1) Strongly disagree, (2) Disagree, (3) Neither disagree nor agree, (4) Agree Strongly and (5) Agree. Additionally, we added the sixth option (6) Not applicable so the participants can opt-out of the question.

The interview questionnaire was developed in 3 months (as shown in Table 1). An initial draft (version 1) of the survey was first created based on the literature in software engineering and COVID-19. The first survey was created in Google forms. The second version of the survey was made after taking into account comments and adjustment from the whole author team. Some changes in later versions of the survey, for instance, re-coding scale labels of some questions, removal of few questions for better focus, adding team size/ company size value of 1 for filtering, adding open-text questions, and adding the option 'Not applicable' in questions.

A pilot data collection was done in April 2021. We gathered responses from 25 teams to validate our constructs, scales and questions. We also asked for expert opinions from senior researchers in software engineering who conducted survey research before.[20,56] The final survey was made ready on May 2021 and available via the Lime survey tool. The major changes made to versions of the survey is shown in Table 1. The details of the questions are available online[§].

We have several questions helping us to determine whether a company is a startup or an established one.

We also implemented filtering questions to make sure only people who feel the impact of COVID-19 on their professional activities will continue filling in the survey: "Do you experience or observe an impact of COVID-19 to your work/ your company to any extent"

The English version of the survey was translated into seven languages, which are Italian, Spanish, Portuguese, Arabic, Indonesian and Vietnamese. The translation was done by seven core members of the author team. The number of responses in each language is shown in Table 2.

[§]https://COVIDnse.limesurvey.net/561361?lang=en.

TABLE 2 Number of responses by local languages.

Survey language	No. of responses
Italian	5
Arabic	7
Indonesian	11
Chinese	12
Spanish	13
Vietnamese	42
Portuguese	90
English	394
N=	574

3.3 | Sampling strategies

We have tried several ways to purposefully gather a sample that can represent our target population. At the country level, we have had contact from 13+ countries, and we expected to get 10–20 responses per country via these personal channels. Conveniently, we invited participants through our professional and social networks. The invitation message was shared through co-authors' social media, that is, LinkedIn, Twitter, Reddit, Quora, and Facebook. We also published the call for participation in several academic communities, that is, SEWorld, ICSOB, Software Startup Research Network, and so forth. We also explored our professional connections by asking co-authors to send invitation emails to those who they think are likely able to participate. We capitalized on each author's local knowledge to reach more people in their jurisdiction. Rather than a single, global campaign, we used a collection of local campaigns. Each localization involved small changes in wording. In some cases, authors printed out the survey and disseminated the paper-based version instead. We also recruited participants from professional channels, such as Prolific[¶].

3.4 | Data collection

The data collection process started in March 2021 and ended in August 2021. In an invitation-based approach, we invited one respondent as a representative of their teams. In a broad call for participation, we tried to control the sample representatives. Invitations led to a central survey tool, which can be configured to a suitable language version. The survey was spread over five online pages. As shown in Figure 3, a total number of 574 responses were collected. 324 respondents were able to complete the survey (the data inclusion rate is 43.55%). The completion time ranged from 4 to 155 min.

A screening question was asked in the first place before other questions. If a respondent did not observe an impact of COVID-19 to their working environment in some ways, he or she is navigated to the end of the survey. In this way, the survey only gathers opinions from people who actually experienced the change to their working setting. As shown in Figure 4, 290 people (50.5%) answered 'Yes', while 90 people (15.7%) answered 'No' to the questions. The rest had either no answer or answered 'do not know'. As shown in Figure 5, the responses came from 35 countries, and were dominated by respondents from Brazil, UK, Vietnam, USA, and Poland. After filtering irrelevant and invalid responses in the data preprocessing step (section 4.5.1), the number of valid responses for analysis is 297 responses.

3.5 | Data analysis

We received 574 total responses, and after data pre-processing steps, 297 valid responses remained.

[¶]https://prolific.co/.

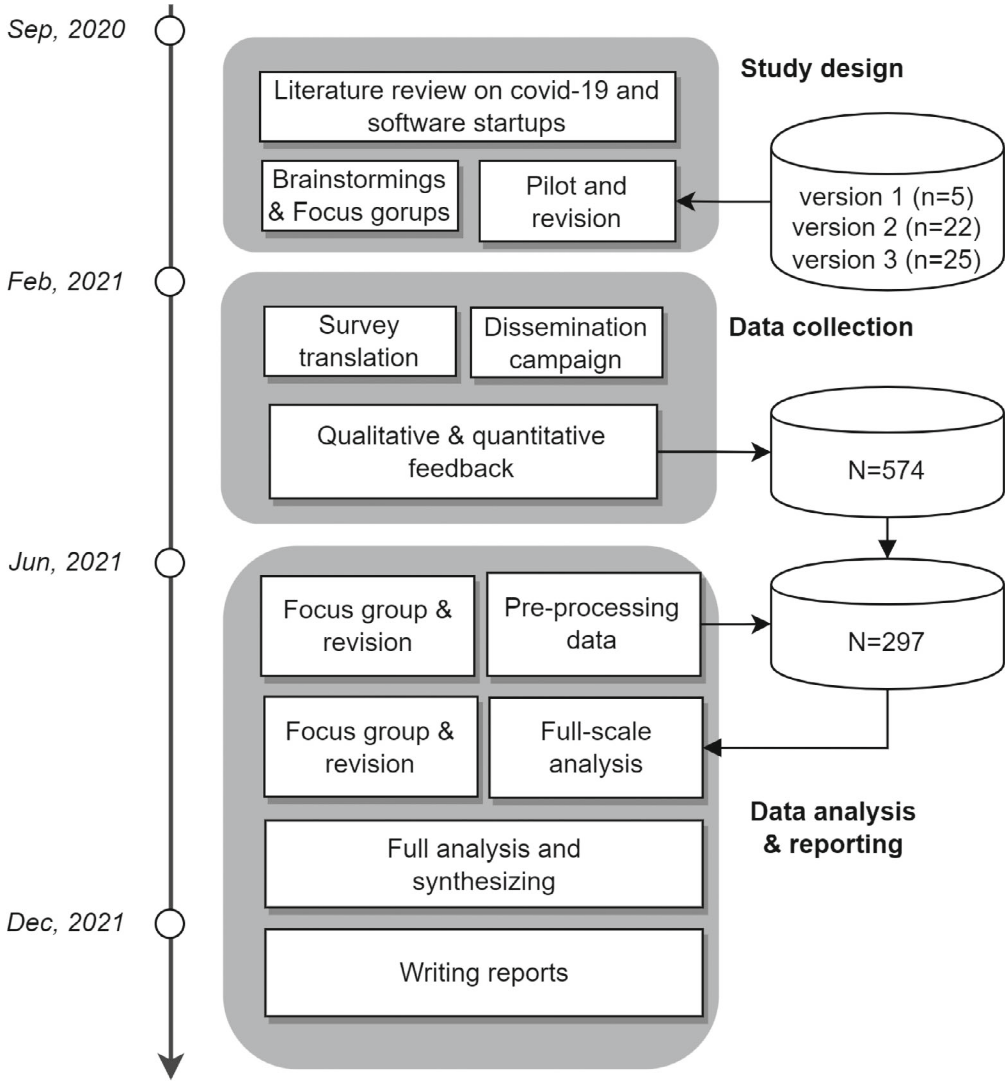

FIGURE 3 Research process.

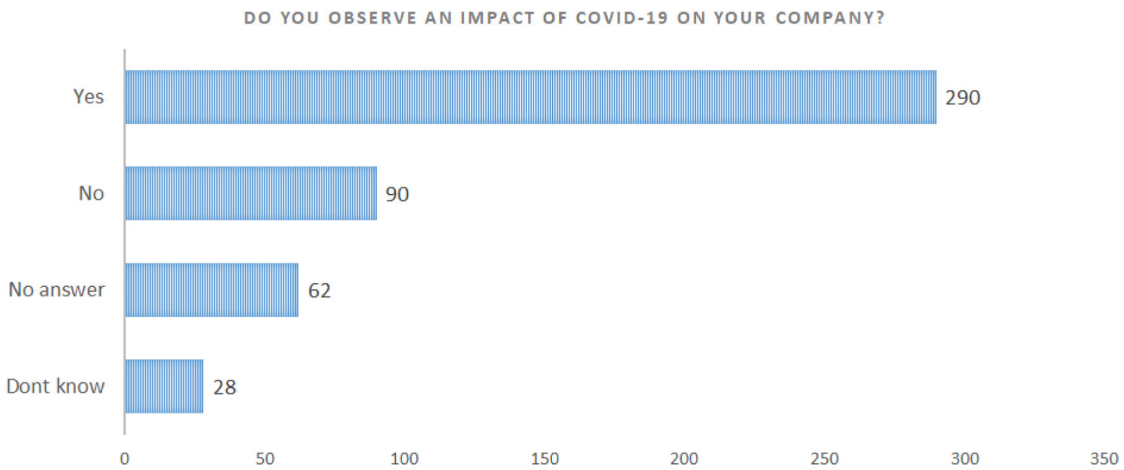

FIGURE 4 Responses of a screening question on the impact of COVID-19.

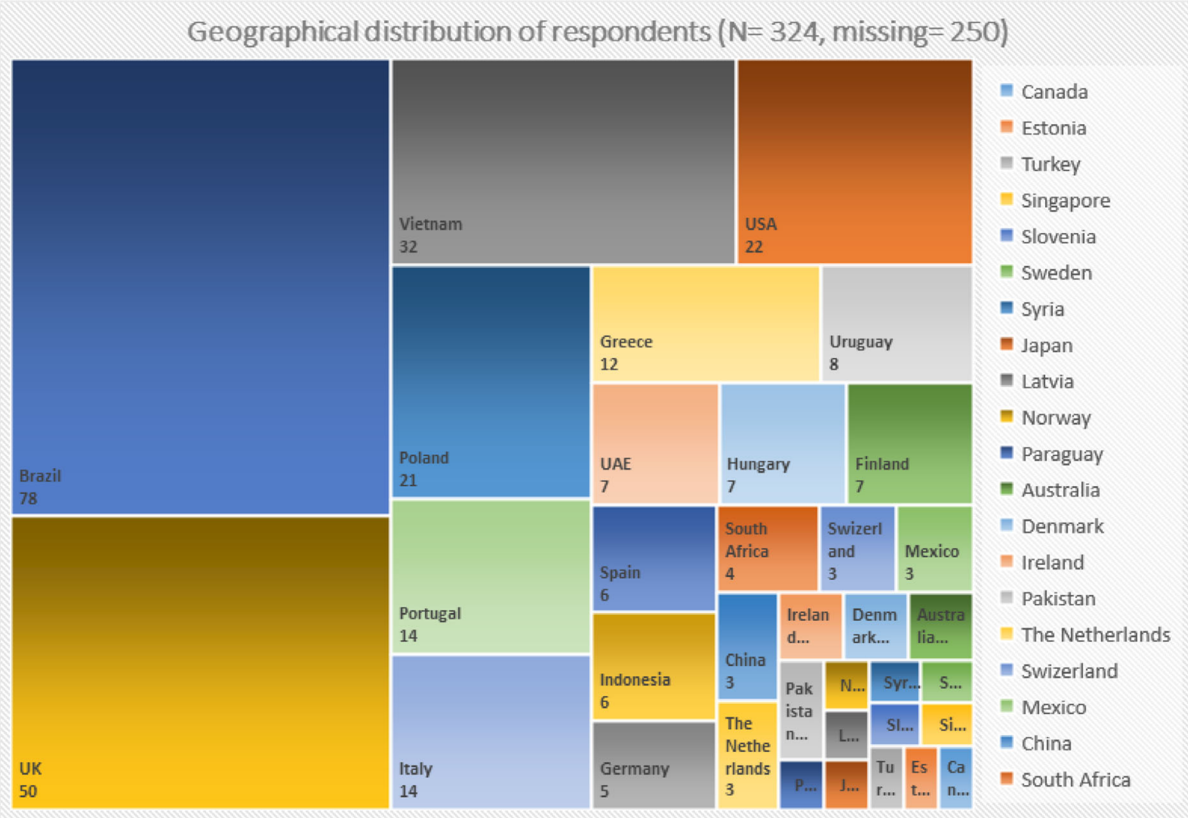

FIGURE 5 Graphical distribution of survey respondents.

3.5.1 | Data pre-processing

The following steps were taken for data pre-processing:

1. Remove responses with almost all empty answers, where the respondent apparently answered the filter question correctly, then skipped all other questions.
2. Remove responses with almost all default answers, meaning that questions were not read properly
3. Exclude responses with exceptionally long or short completion times. In our pilot study, we determined a reasonable time range for manually generated responses. Subsequently, we organized the responses by completion time and eliminated one percent of the total responses from both extremes. As a result, any responses completed in under 3 min or exceeding 155 min were omitted.
4. Remove responses from one-person teams (we had one question to identify team size)
5. Filter out responses that do not experience any changes due to the pandemic
6. Move all free-text responses to a separate file for qualitative analysis
7. Re-code raw data. We re-coded team size to categorize them into either small team versus large team contexts. We re-coded the company type (startup vs. established company), as described in section 4.5.2.
8. Re-code all quantitative answers to the numeric value for quantitative analysis

3.5.2 | Identifying startup companies

To allow comparative analysis, we need to have a way to identify startup companies. A challenge is that the term startup can be interpreted differently by people, especially when respondents are spread around the world. We asked different questions to identify the company's situation. Among 297 valid respondents, 97 of them are classified as startup companies, and 181 of them are classified as established companies. There were 19 cases where we could not identify the company type.

TABLE 3 Number of startups versus established companies.

Company type	No. of responses
Startup	97
Established	181
Unknown	19
N=	297

TABLE 4 Questions about contexts and coded variables.

Questions	Value range	Coded value
What is the size of your team that you work?	Less than 10 people	Small
	Equal or more than 10 people	Large
How long has your company existed	Less than 10 years	Newly established
	Equal or more than 10 years	Long-time established
In which city and country are your operations based?	Different cities	America versus Latin America versus Europe versus (Asia & Australia) versus Africa

Based on our definition (Section 2.3), we determined if a company is classified as a startup basing on the respondent's perception, the state of their main product and the company size. The distribution of company types is shown in Table 3. The classification was done using a pre-determined set of rules shown in Appendix A.

We also re-coded other contextual variables into categories as shown in Table 4.

3.5.3 | Quantitative analysis

For RQ1 to RQ4, we conducted descriptive statistics to describe the distribution of respondents' answers. The survey data was pre-processed and recoded (as described in Section 3.5.1) before conducting analysis and visualization to answer these questions. With RQ4, we need to compare respondents' answer among different categories. Because the dependent variable and independent variables are measured as categories at the ordinal level, a Chi-square test will be used to assess the the significance of difference between groups.

3.5.4 | Qualitative analysis

We extracted qualitative data from 17 open-ended questions. The analysis is not fully inductive, as we have some pre-determined points we want to observe, including a description of WFH arrangements, reasons for adopted tools and practices, reasons for negative, neutral and positive perceptions on the impact of WFH on project management and software engineering. In total, there were 27 categories identified from the structure of the survey questionnaire. We applied a tailored thematic analysis, which is commonly seen in empirical SE research.[57,58] These categorical themes guided the axial coding process. A total of 521 codes were obtained that were in English, Portuguese, Italian, Spanish, and Vietnamese languages. Text that was not relevant or did not give any useful content was excluded. There were 121 codes for WFH, 84 codes for Project Management, 92 codes for Software Engineering activities, 134 codes for Innovation, and 107 codes for Resilience. The analysis process is shown in Figure 6.

4 | RESULTS

This section presents answers to our RQs presented in Section 1 (Section 4.1 to RQ1, Section 4.2 to RQ2, Section 4.3 to RQ3, and Section 4.4 to RQ4). At the end of each section, we summarize key findings in the section in the form of primary observations (POs). The POs help to directly address the research questions and provide implications from the studied population.

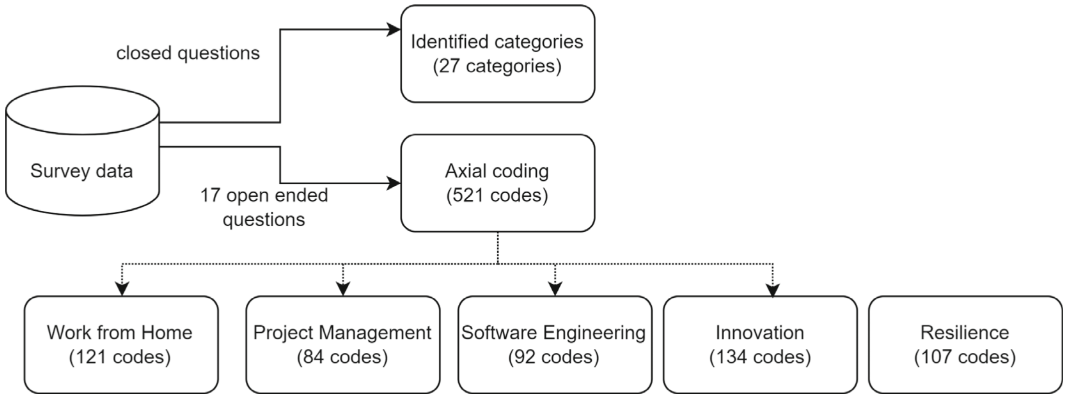

FIGURE 6 Axial coding process and outcomes.

4.1 | RQ1–How does the way of working in software teams change when WFH is adopted?

Our data reveals the change to teams' way of working in three areas (1) distributed work arrangement, (2) collaboration and communication tools, and (3) coordination and control mechanisms.

4.1.1 | Distributed work arrangement

We reported how the collaborative working mode had changed for respondents in three categories (teamwork across geographical locations, teamwork across time zones and collaboration with external stakeholders). Figure 7 presents the observed shift working trends in percentage. For instance, there is an (expectedly) significant reduction in the percentage of people who collocated in the same office (from 51.9% to 16.9%) and in the percentage of people who collaborate physically in the same building (from 24.7% to 13.8%). The virtual collaboration with stakeholders (i.e., customers, vendors, etc.) who are in different cities or same time zones has increased to some extent (from 22.3% to 33.5% and from 30.3% to 37.1% correspondingly). There is little change in the timezone category, that is, small increase in teamwork in different time zones.

PO1: The WFH arrangement is characterized by geographical shift (mainly from offices to home), and increased internal collaboration within and across time zones. External collaboration does not significantly change in the new working mode.

4.1.2 | Collaboration and communication tools

Communication and collaboration practices are reported in the context of digital tools. Table 5 presents the categories of collaborative tools in order of their popularity. Video conferencing has the potential to replace or supplement conventional forms of communication. Participants expressed the various use scenarios of conferencing tools, with different features, such as whiteboarding, screen sharing, screen annotation, group chat and breakout rooms. Virtual synchronous communication is also supplemented by interactive tools such as Mentimeter and Miro board.

In combination with a synchronous communication tool, many organizations defined an asynchronous one as internal communication channels. Microsoft Teams, WhatsApp, Slack, Viber and Discord are among the most common messenger tools for work. Such tools can compensate for the lack of opportunities for ad-hoc communication, and become an informal communication bridge for all members of a project. The increased use of instant messaging might not be a

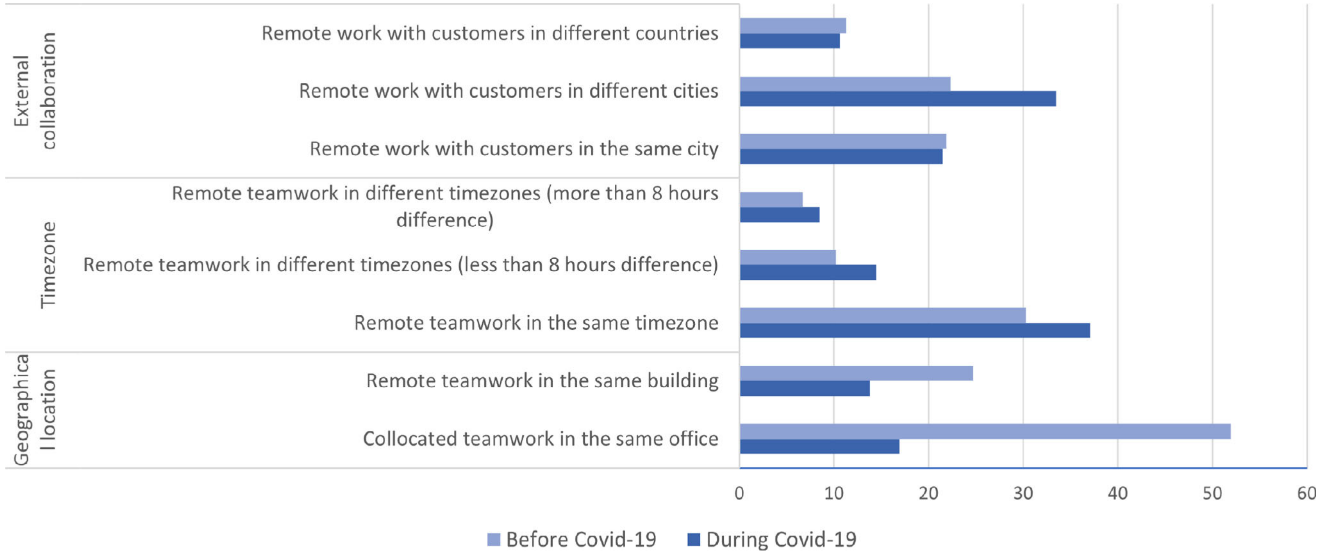

FIGURE 7 WFH arrangement across geographical, temporal and team boundary.

TABLE 5 Summary of commonly-used communication and collaboration tools.

Category	Description	Examples	% responses
Video conferencing	Cloud-based communication services that facilitate virtual meeting with audio, video among few to many participants. Calls can be made from various types of devices	Teams, Zoom, Meet, Skype, WebEx, Chime, Spaces	87%
Instant messaging	Asynchronous communication with additional features for teamwork, that is, file sharing, channels, search and people tag	MS Team, Whatsapp, Slack, Viber, Discord, FB Messenger, Brosix, Line	80%
Cloud storage	Cloud platforms that enable storage and collaborative editing of documents or files	Private clouds, One drive, Google drive, Dropbox	58%
Calendar sharing	Tools that enhance remote collaboration and get teams on the same timeline	Outlook, Google calendar, iCloud, Monday	55%
Project management tools	Organize teamwork according to project management areas	MS Project, MS Team, Trello, Basecamp, Monday, Jira	48 %
Version control systems	Systems to keep tracks of changes to source code and documents	Git, CVS, SVN, TFS, Mecurial, Bitbucket	45 %
Social media for work	Tools to share information and facilitate communications with internal and external	Facebook, LinkedIn, Twitter	24 %
Collab tools for specialized tasks	Collaborative platforms that remote developers can jointly work	Visual Studio, Google Collab, AWS Cloud9, Codepen, Adobe Illustrator	18 %

temporary measure during the pandemic due to its complementary benefits: "*We are embracing more collaborative tools for documentation; with so much communication online, people are more likely to use email/chat instead of calling meetings, allowing clients and developers to communicate more flexibly*" (Respondent389)

Our surveys also revealed other categories of tools, including calendar sharing, project management, version control systems, social media and collab tools, and their popular example tools, as shown in Table 5. It is interesting to see the names of social media, such as Facebook, Twitter and LinkedIn at work. One of the respondents has stated: "*Increased use of chat and social media tools means developers facing issues can ask any colleagues regardless of their location for input/advice*" (Respondent371)

PO2: There is a wide range of tools being used to support collaboration and socializing during WFH. The top four collaborative types of tools are video conferencing, instant messaging, cloud storage and calendar sharing.

4.1.3 | Coordination and control mechanisms

Many respondents described a significant change from organic coordination to mechanistic coordination in the WFH context:

1. "*Members of my team are now, more than ever, required to document everything they do in order to let other members of the team know what they are working on. That's positive. On the other side, brainstorming and interviewing people takes place remotely, making it harder to do effectively*" (Respondent380)
2. "*We had calls and meetings before COVID-19, a lot of informal meetups and syncs were done in the office but now they have to be planned, scheduled, and organized. It slowed down some stuff that usually was very easy to solve*" (Respondent17)

Among the top 10 new coordination mechanisms introduced in software projects during the pandemic time, seven are mechanistic approaches, which are characterized by high centralization, complexity, and formalization (Figure 8). Adaption (in most cases increasing) of formal meeting frequency is the most commonly reported approach. To compensate for the lack of physical appearance, the respondents reported an increase/ new adoption of micro-level controls, such as daily reports (formally or informally), daily work hour registration, and camera on while working. In many projects, new roles are assigned to support the virtual collaboration process. Such roles might overlap with emerging boundary spanners in virtual space.

The only organic coordination practice in the top ten is using social media for team collaboration. The benefit of social media is stated by developers: "*Increased use of chat and social media tools means devs facing issues can ask any colleagues regardless of their location for input/advice*" (Respondent371), or "*Social media became stronger due to COVID, as a way to*

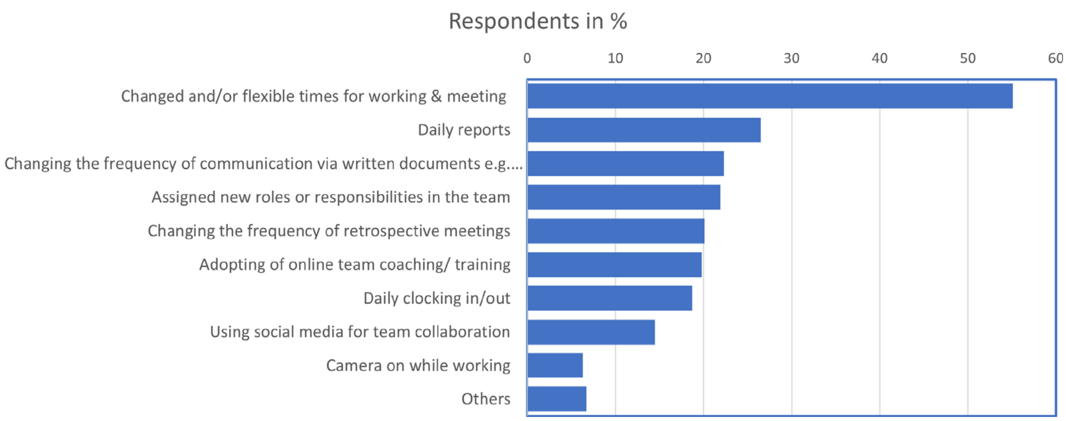

FIGURE 8 Distributions of adopted coordination and control mechanisms.

communicate. An important next step was recognizing this way of communicating and integrating into work practices after the pandemic has gone" (Respondent507).

PO3: Different mechanistic coordination approaches are introduced and implemented for WFH besides the adoption of online training and social media for work.

4.2 | RQ2: How is project management impacted when WFH is adopted?

We included in our survey several questions about project management practices in connection to the shift of work arrangement. Figure 9 displays the respondents' ratings in four dimensions, which include:

1. ability to acquire needed competence
2. ability to maintain organizational culture and spirit
3. ability for up-front project planning in term of resources, time, risk and milestones
4. ability to maintain overview of who-does-what

Overall, we observed a mixed result of both positive and negative rates on the impact of work changes on project management. Nonetheless, it is notable that respondents tended to encounter greater challenges in the realms of project planning and the preservation of organizational culture when compared to other facets of project management activities.

We asked whether the new working condition led to a delay in their current projects. 47.2% of all respondents admitted some delays occurring in their current projects due to the shift. 13.4% experienced significant delays and 3.2% had their projects terminated. There were only 25% who saw no impact on their project timeline.

PO4: It is a mixed picture of how software project management is affected by the new work arrangement. Team and task awareness do not seem to be a problem. It is perceived as more difficult for project planning than it was before.

4.3 | RQ3: How are software engineering activities impacted when WFH is adopted?

We included in our survey several questions about how are the software engineering roles affected due to the new working environment. We expected respondents to reflect on their own roles or observe other roles in their projects. Seven common

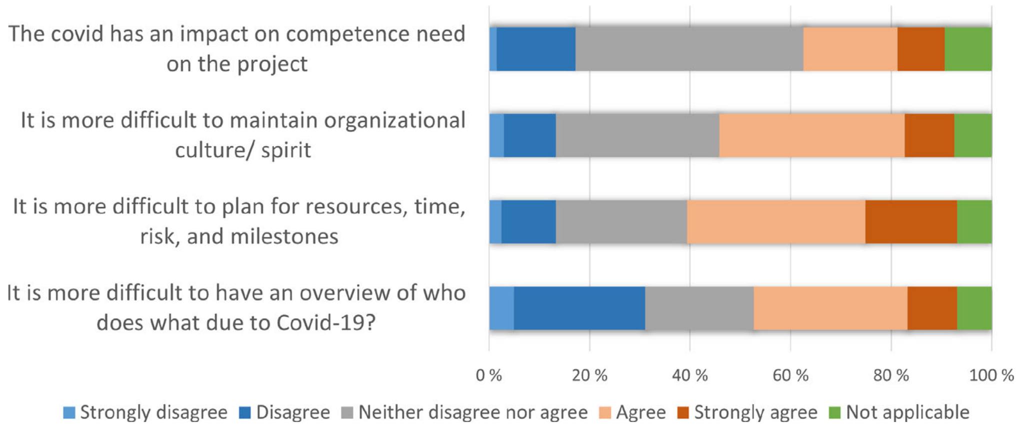

FIGURE 9 The perceived impact of WFH on project management activities.

software engineering roles are asked, including Software Architect, Software Developer, Tester, UX Designer, Business Analyst, Project Manager and Scrum Master. The result is shown in Figure 10. For all software engineering roles that were named, there was a large portion of responses stating a neutral impact (from 37.4% to 51.2%). Overall, we also observed a relative balance between the negative and positive rates on the impact of WFH on software engineering roles.

4.3.1 | Requirement engineering

The distribution of respondents rates on requirement engineering activities is shown in Figure 11. We observed more responses with negative or little negative impact in activities like requirement gathering and customer involvement than that in activities like requirement prioritization and management.

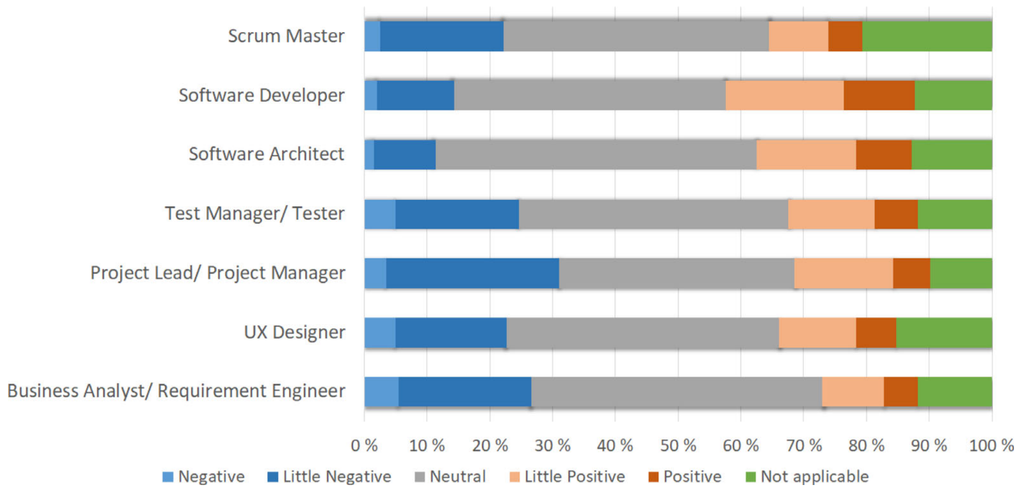

FIGURE 10 The perceived impact of WFH on software engineering roles.

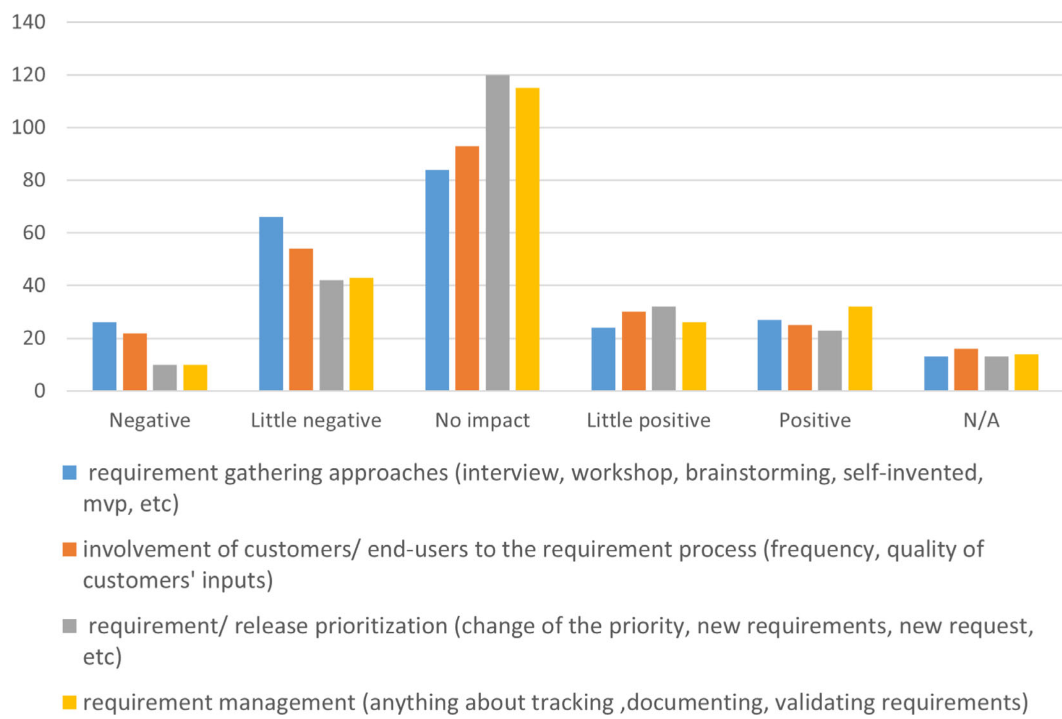

FIGURE 11 The perceived impact of WFH on requirement engineering activities.

Negative impact can be found in the areas requiring customer involvement when shifting from a physical manner to a remote approach. Several respondents have commented in line with this observation, for example: *"For customers, soliciting feedback has become laborious when done remotely, so mainly a time issue*" (Respondent60, UK), or "*A lot of documenting that wasn't noticed until COVID-19. More impact on gathering approaches–various meetings help organize work*" (Respondent26, Poland) or *"Hard to get hold of stakeholders/customers since they are not in their office*" (Respondent140, Latvia), or "*We had calls and meetings before COVID19 but a lot of informal meetups and syncs were done in the office but now have to be planned, scheduled, and organized. It slowed down some stuff that usually was very easy to solve*" (Respondent17, Mexico) and "*We think that doing an interview or understand our clients' problems by using programs as Zoom instead of meeting in person may reduce the effectiveness of the reunions*" (Respondent247, Uruguay).

PO5: The impact of WFH on requirement engineering tends to be more negatively perceived in activities like requirement gathering and customer involvement than in activities like requirement prioritization and management.

4.3.2 | Software architecture

The distribution of respondents' perception on the effect on software architecture activities is shown in Figure 12. Compared to other roles, scientists and architects in a software project have more reported neutral or positive experiences. This includes (i) more focused time (given less spent on communication or travel) as typified by this response, *"The development team has more research time and spends more time on design*" (Respondent 101); (ii) greater flexibility as illustrated by this response, *"Our business was set to a halt and so they programmers were more efficient and were able to test new methods. The fact that they worked more flexible hours reduced costs greatly*." (Respondent 373, Germany) and (iii) better respect of formal processes as demonstrated in this response, *"In adaptation process, we got better in listen and internal communication. The team is more cohesive and working on making standard processes better and nail it on that. All of them are more creative and productive*."(Respondent 291, Brazil). An established technical setting for complex tasks like architecture is

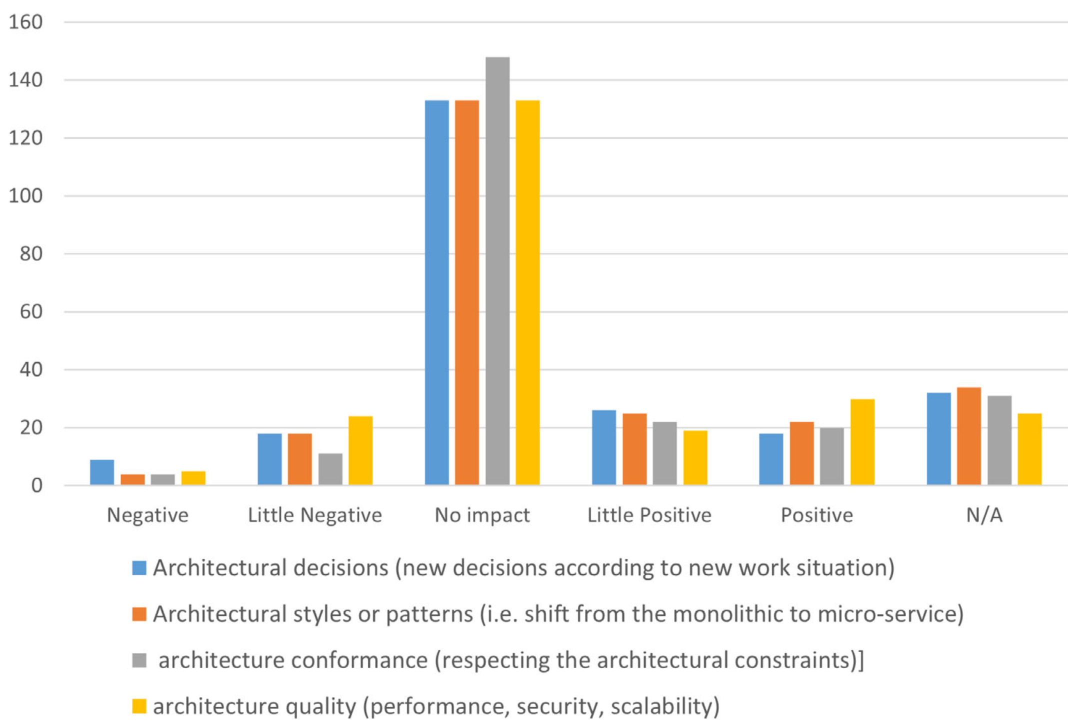

FIGURE 12 The perceived impact of WFH on software architecture activities.

essential to maintain productivity in a new working mode: *"Since the target architecture and design was set up during the project initiation phase, the development process was able to align seamlessly to it. Since all developers are experienced in the standard architecture, the alignment to architecture was never an issue. Any open questions were always flagged in the online daily standup meeting and closed quickly.*" (Respondent 423, UK)

PO6: Compared to other SE activities, software architecture shows the least impact by WFH. Many acknowledge the positive impact of WFH on architectural activities and quality.

4.3.3 | UX design

UX work also shares a common challenge with other roles in a WFH context as shown by several comments: *"Interaction with users and customers during the pandemic has become quite complicated given social distancing*" (Respondent 348, Vietnam), or *"Testing has become harder because people can't come to the office and user validation has to be done online only*" (Respondent 364, Brazil). Some parts of UX work is not even possible in a WFH setting for example, *"More difficult to have customers test on the devices we would like to use as they are only available in the office*" (Respondent 382, Italy). An established process is reported as a factor to determine the quality of UX work online: *"UX is being integrated into our planning process earlier than it used to be; our overall organization is also implementing web compliance and accessibility guidelines more stringently*" (Respondent 371, UK). Some UX designers enjoy the flexibility of WFH and see an alignment with creativity which is essential for their work: *"Designers were able to perform better due to working from home and being flexible on their schedule. Zoom was pretty essential when they needed to cooperate.*" (Respondent 373, UK)

4.3.4 | Software implementation

The distribution of respondents' responses on implementation activities is shown in Figure 13.

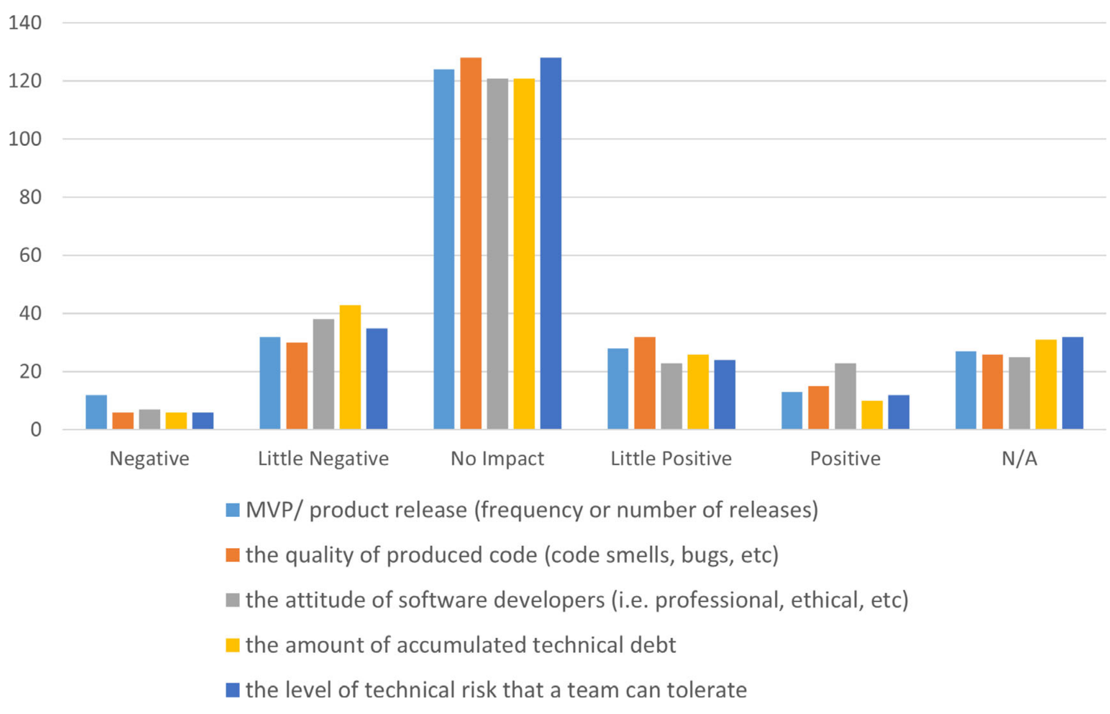

FIGURE 13 The perceived impact of WFH on implementation activities.

Regarding Software developers' responses, many have mentioned their wellbeing during the pandemic time, for instance, *"Attitudes have suffered with declining mental health and isolation"* (Respondent 11), or *"We struggled a bit with energy due to not meeting up and generally living through a lockdown and torturous lack of things to do"* (Respondent 216, Brazil). We also documented challenges regarding the maintenance of code standards, as stated in this comment:*"In general, due to frequent changes, less care was taken with quality metrics or it was not possible to reach a satisfactory level of these metrics due to the short time, despite efforts to guide the team to maintain the standard."* (Respondent 202, UK), or *"Problems that occur in remote work do not have the same urgency as they do in face-to-face work. As well as the charge for code quality has decreased."* (Respondent 315, Brazil) or *"... releases slowed due to adaptation to change. Tech debt increased to do things quickly to deliver for customers facing exceptionally challenging conditions."* (Respondent 539, Greece)

> PO7: It is a mixed picture of the impact of WFH on software implementation. Both negative and positive impacts are found on the impact on frequency of releases, quality of code, developers' attitudes, accumulated technical debts and technical risks.

4.3.5 | Quality assurance

The distribution of respondents' responses on quality assurance activities is shown in Figure 14. It is quite interesting to see many testers with negative experiences with WFH. One reason might be that, the testing process can be time-consuming, procedural and relate to a range of different people and functions, needing a lot of communication. Such communication can be negatively impacted due to the change in working mode. A test manager stated, *"They usually were done by a team so again, its new meeting scheduling, new organizations, more time going into them, etc"* (Respondent119, Turkey). The impact can also come to the quality of testing, for instance, *"The testing team began to develop and change tests 'to pass' instead of actually testing what was supposed to be tested."* (Respondent198, Paraguay), or *"We don't have many accurate tests or even*

FIGURE 14 The perceived impact of WFH on quality assurance activities.

lack of tests on some products" (Respondent 246, Brazil). The issues with testing are also found with acceptance testing as stated in these comments: *"Users had greater difficulty in validation and acceptance tests remotely when they did not fully know the product*" (Respondent 290, Brazil) or *"Same point about communication between teams, this new modality of work has worsened the effectiveness of current code inspection (code review, walkthrough, etc) and the effectiveness of current user acceptance testing activities.*" (Respondent 348, Vietnam). A senior tester stated *"Automated testing ensured that there was no change in testing practices before or after COVID. Code review and acceptance got tougher and more time had to be invested in it, since communicating this feedback online was much more time intensive. The team had to be trained to perform this online. Earlier, it was much easier to interact, wherein we could just walk to the desk to discuss or get feedback.*" (Respondent 423, Japan).

PO8: It is a mixed picture of the impact of WFH on software testing. Both negative and positive impacts are found on development testing, user testing and code inspection.

4.3.6 | Software process

Regarding process experts, it seems that more managerial work and responsibility occur during the shift in team working conditions, for example, "*About management work, it is harder to co-ordinate activity and to communicate with everyone.*" (Respondent70, UK). Many project managers shared difficult experiences in working with not only their teams, but also external stakeholders, for instance, *"The pandemic has taken its toll on us so everything is a little more difficult than it used to be, including communication, the feel of being a team, interviews about a place in our company*." (Respondent82, Greece), or *"Not being physically in the same room impinges upon the sharing of ideas and suggestions, it feels less natural and so it seems slightly stifled as a creative working environment*" (Respondent260, Pakistan). Coordination also suffers when WFH intervenes or disrupt traditional task-dependencies for example, *"Despite the demands, there is still a lot of accumulated technical debt that is yet to be resolved but, for technical reasons, we still cannot start the improvements before some tasks*" (Respondent 246, Brazil).

Having a process in place is essential to overcome many of the above-mentioned challenges: *"MVPs took longer than expected since UX designs were always getting delayed. Initially, it was tough to collaborate on everything online, and this caused some friction within the dev teams. However, since all tests are automated, we were able to align to the existing testing methodology and it didn't make any difference to be performed online or on-premise. With Agile methodology being practiced, it was easy to flag potential technical risks early in the cycle and work out mitigation plans.*" (Respondent 423, UK)

PO9: Processes and practices that embrace the adoption of tools are important to reduce many of the negative impacts of WFH on Software Engineering activities.

The respondents are also asked about the impact of WFH on the amount of time spent on different Software Engineering activities. Figure 15 shows a consistent response pattern across software engineering activities. The majority perceived no change in time spent on these tasks. There are relatively more people who perceived a slightly increased amount of time needed on Requirement Engineering, Architecture, UX Design, Coding and Testing.

P10: All Software Engineering tasks tend to take more time to complete than before.

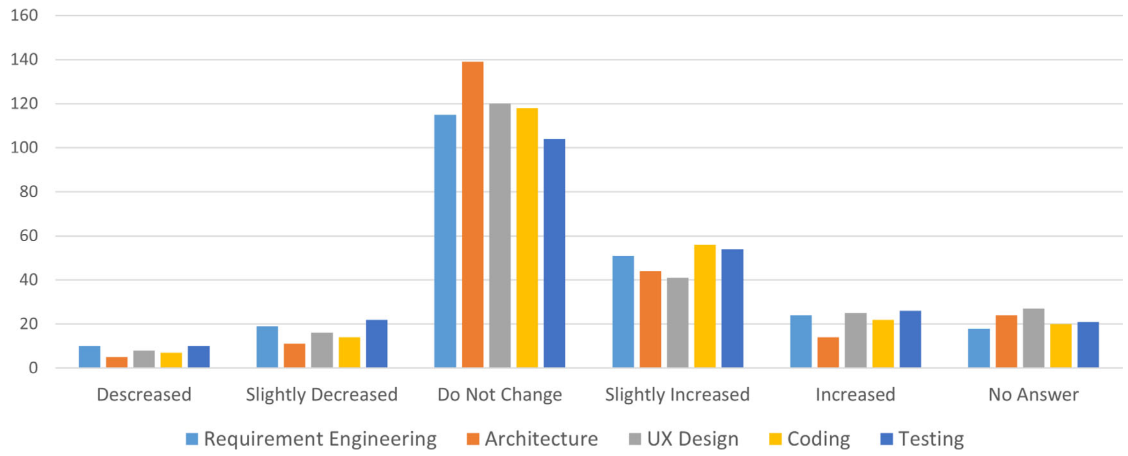

FIGURE 15 The perceived delay in software engineering task durations.

4.4 | RQ4: Is there any difference between startups and established companies regarding the above impact?

To investigate the possible relationship between types of software companies (startups vs. established companies), we conducted a chi-square test of Independence. This is a non-parametric hypothesis test that allows the conclusion on the relationship between two variables. We will test two set of hypotheses as follows:

1. $H1_0$: There is no difference between startups and established companies in the observed impact of WFH and project management
2. $H1_a$: There is a difference between startups and established companies in the observed impact of WFH and project management

as explored in Section 4.4.1 and

1. $H2_0$: There is no difference between startups and established companies in the observed impact of WFH and software engineering activities
2. $H2_a$: There is a difference between startups and established companies in the observed impact of WFH and software engineering activities

as explored in Section 4.4.2.

We also investigate the possible difference among the observations between three other contextual variables: project size (small vs. large teams), company age (recent vs. long-time companies) and geographical locations (Europe and North-America, South-America, Asia and Africa).

4.4.1 | Project management

The p-values of chi-square results are displayed in Table 6. The significant values are marked * for $p \leq 0.05$, ** for $p \leq 0.01$ and *** for $p < 0.001$. Among four aspects of project management, none of the test for company types have a significant chi-square value, hence, we can not reject the null hypothesis $H1_0$.

An interesting observation is that geographical location can have relations to the perceived impact of WFH on project management. Table 6 showed significant p-values in three out of five project management aspects (organizational culture, competence needs and project delay)

The perceived impact of changed work arrangements and competence needs can be different between small and large teams, between company newly established and long-time companies and between companies in different continents.

TABLE 6 Chi-square test results for four contextual variables on project management.

Questions	Startups versus Established	Small versus large team	Recent versus long-time companies	Among continents
It is more difficult to have an overview of who does what	0.329	0.352	0.453	0.427
It is more difficult to plan for resources, time, risk, and milestones	0.353	0.102	0.370	0.182
It is more difficult to maintain organizational culture	0.194	0.384	0.580	0.015*
WFH as an impact on competence needs in the project	0.033	0.002**	0.003**	<0.001***
The experienced delay in projects due to the shift to WFH	0.893	0.196	0.605	0.043*

*$p \leq 0.05$;
**$p \leq 0.01$;
***$p < 0.001$.

TABLE 7 Chi-square test results for four contextual variables on software engineering.

SE activities	Startups versus established	Small versus large team	Recent versus long-time companies	Among continents
Requirement engineering	0.295	0.294	0.436	0.001**
UX Design	0.122	0.104	0.457	0.047*
Architecture	0.574	0.300	0.662	0.017*
Coding	0.384	0.440	0.384	<0.001***
Testing	0.748	0.660	0.971	0.158
Process (Scrum)	0.815	0.389	0.351	<0.001***
Project management	0.610	0.609	0.260	0.023*

*$p \leq 0.05$;
**$p \leq 0.01$;
***$p < 0.001$.

4.4.2 | Software engineering

The p-values of chi-square results are displayed in Table 7. The significant value is marked * for $p \leq 0.05$, ** for $p \leq 0.01$ and *** for $p < 0.001$. Among seven areas of software engineering, none of the tests for company types have a significant chi-square value; hence, we can not reject the null hypothesis $H2_0$.

We also observed the effect of geographical location variables, as significant p-values are found in six out of seven software engineering activities (requirement engineering, UX Design, architecture, process and Project Management).

The perceived impact of WFH and competence needs can be different between small and large teams, between company newly established and long-time companies and companies in different continents.

P11: There is no significant difference found in the impact of WFH on Project Management and Software Engineering activities between startups and established companies.
P12: There is a significant difference in the impact of WFH on Project Management and Software Engineering activities among software companies in different continents.

5 | DISCUSSION

The summary of our findings is given in Table 8. In this section we discuss how our findings relate to existing studies, threats to validity and implications for research and practice.

5.1 | Answering and discussing the RQs

The findings for each RQs and discussion in line with existing studies are given in Sections 5.1.1 to 5.1.5

5.1.1 | RQ1: How does the way of working in software teams change when WFH is adopted?

By filtering participants without awareness of changing work situations in their companies, we acquired the data set of 297 respondents who experienced the impact of COVID-19 and changing work arrangements on their software development projects. Previous work in GSD has described a distributed work setting in five dimensions: geographical, temporal, cultural, work and organizational dimensions. The shift in working patterns happened mainly in geographical dimensions, with project team members moving from offices to fully or mostly WFH situations. The extent of external collaboration seems to have remained the same during the pandemic time. The amount of internal collaboration increases over temporal dimensions. The amount of external collaboration (i.e., interaction with customers) has not significantly changed (PO1).

TABLE 8 Summary of the findings.

POs	Research findings	RQs
PO1	The WFH arrangement is characterized by geographical shift (mainly from offices to home), and increase internal collaboration within and across time zones. External collaboration does not significantly change in the new working mode	RQ1
PO2	There are a wide range of tools being used to support collaboration and socializing during WFH. The top four collaborative types of tools are video conferencing, instant messenger, cloud storage and calendar sharing	RQ1
PO3	Different mechanistic coordination approaches are introduced and implemented for WFH besides the adoption of online training and social media for work	RQ1
PO4	It is a mixed picture of how software project management is affected by the new work arrangement. Team and task awareness do not seem to be a problem. It is perceived as more difficult for project planning than it was before	RQ2
PO5	The impact of WFH on requirement engineering tends to be more negatively perceived in activities like requirement gathering and customer involvement than in activities like requirement prioritization and management	RQ3
PO6	Among SE activities, software architecture shows the least impact by new work arrangement. Many acknowledge the positive impact of WFH on architectural activities and quality	RQ3
PO7	Both negative and positive impacts are found on frequency of releases, quality of code, developers' attitudes, accumulated technical debts and technical risks	RQ3
PO8	Both negative and positive impacts are found on development testing, user testing and code inspection	RQ3
PO9	Processes and practices that embrace the adoption of tools are important to reduce many of negative impacts of WFH on Software Engineering activities	RQ3
P10	All Software Engineering tasks tend to take more time to complete than it was before	RQ3
P11	There is no significant difference found on the impact of WFH on Project Management and Software Engineering activities between startups and established companies	RQ4
P12	There is a significant difference in the impact of WFH on Project Management and Software Engineering activities among software companies in different continents	RQ4

The increased amount of collaboration over the Internet is supported by the increased addition of a wide variety of collaborative toolsets (PO2). In addition, different mechanistic coordination approaches, social media and online training are introduced in many projects to compensate for the lack of physical appearance (PO3).

We observed connections between PO2 and PO3. Coordination mechanisms (i) define how collaborative tools can be used, for example, setting frequency for working sessions or meeting online; (ii) support achieving effectiveness from collaborative tools, for instance, 'Camera on while working/meeting' linked to the adoption of video conferencing tools; and (iii) are enabled by the collaboration in place, that is, online coaching and training via video conferencing and collab tools. It seems that tools and processes are integral to the new working arrangements, and WFH is not a completely novel situation.

5.1.2 | RQ2: How is project management impacted when WFH is adopted?

Project teams are equipped with new/ enhanced adoptions of collaboration tools and coordination and control mechanisms (from RQ1). In this context, respondents still report an additional project delay during the pandemic time. This aligns with the tendency for longer software engineering task durations observed in PO10. However, we are not able to distinguish between projects that started before COVID-19 (in other words, the work arrangement shift occurred in the middle of the projects), or projects that started during the COVID-19 time.

A majority of respondents have agreed on the difficulty of planning resources, scope, time and risks in the WFH environment. This may not be a surprise since greater uncertainties and reduced visibility of changes are expected in this work arrangement.

Project managers seem to not agree on the difficulty experienced in having an overview of who does what in their teams. As this was already documented as a challenge with tool adoption in GSD literature,[59] we can argue that there is a certain level of preparation and maturity in tool adoption that increases the effectiveness of tracing and monitoring software projects.

5.1.3 | RQ3: How are software engineering activities impacted when WFH is adopted

Ford et al. conducted both qualitative and quantitative research on software engineers at Microsoft during Spring 2020.[15] The authors reported a mixed experience for software engineers when working from home. They found that for the same factor, one engineer can perceive it as a benefit and another can perceive it as a challenge. Similarly, Smite and her colleagues conducted a study on software projects and did not observe a significant impact of COVID-19.[17] Our work confirms the previous observations in a larger and more diverse set of global software projects. We documented a majority number of answers of 'no impact' or 'no change' in WFH situations. The tendency of answers with either negative impacts or positive impacts to software engineering activities is noted in the POs PO5 to PO10.

The impact of WFH on requirement engineering tends to be significant and negative on activities involving stakeholder interactions (P5). This agrees with observations from a previously reported study that reports, "Understanding how the system under design will be used is challenging when site visits and observation are unavailable."[60] Our study characterizes these challenges on a large scale.

Software architecture (both decisions and quality) is the least impacted by WFH situations, amongst those activities studied (PO6), followed by software implementation (PO8). Smite et al. revealed that during WFH, software engineers continue committing code and carrying out their daily duties without significant disruptions.[16] The technical nature of the tasks might be less impacted by the social and organizational changes. In many situations, architects and developers enjoyed the flexibility and 'focused time' to improve their work. On the negative side, developers also reported challenges with well-beingness, energy level and work quality.

UX design shares a common challenge with certain requirement engineering activities (customer study, user validation) and general project tasks (lack of physical interaction). The impact of the workplace on creativity during UX design might be a relevant topic to explore, however, we did not acquire enough data to draw further conclusions on that.

Quality assurance shows a mix of negative and positive perceived impacts on both the code inspection development test and user test (PO8) It is relatively more challenging for remote acceptance testing due to new ways of communication between the development team and the users. We observed reported difficult situations when fewer automated tests were in place, where there was lack of mature testing and on-boarding processes and explicit ways to ensure the work quality.

From previous POs, we can argue that processes and practices are important to prepare for WFH, to maintain productivity and quality (PO9). Task dependency might be an important topic for preparing a process for WFH project. Smite et al. and Rodeghero et al. described socializing, communication and collaboration, and onboarding practices that have been adapted to a WFH context.[16,61] While we cover some popular mechanisms in our survey, that is, turn-on cameras, social network for socializing, more meetings, and so forth, we lack insights on their effectiveness.

Kettunen et al. conducted a survey on Agile practices during the pandemic in Sweden and Finland.[62] When asked about the impact of the pandemic impact their companies, the authors reported that 53% of the respondents had perceived negative impacts and 33% of the respondents had perceived positive impacts. Our results tend to align with this observation, but we further provide specific details on which software engineering roles are affected and which aspects are perceived to be either negatively or positively impacted. Agile is also mentioned by some respondents as a useful approach in their new work arrangement. On one hand, the Agile mindset might help in reacting to uncertainties and changes introduced during the pandemic time. On the other hand, Agile does not encourage formal collaboration and plan-driven work, which is shown to be increasingly adopted during WFH. This is an interesting research area that needs more insight.

5.1.4 | RQ4: Is there any difference between startups and established companies regarding the above impact?

It comes as a surprise that no difference was found regarding project management and software engineering (PO11) between startups and established companies. We can suggest three ways to explain this observation. Firstly, software startups might be agile in reacting to influences and that helps to make them as prepared as established companies, who have resources and competence for the process of work adaptation. Secondly, software startups might face the impact of the pandemic in other aspects, such as market and finance. The impact of the pandemic on management and engineering might be overlooked. Thirdly, 'startups' might not be a heterogeneous group and they are perceived and evolve differently in different cultures and locations. Hence, our samples include various 'types' of startups that do not show a common work pattern.

An interesting observation is a relationship between geographical locations and the impact of WFH on both project management and software engineering activities (PO12). This observation might be explained in two ways. Firstly, the impact of the pandemic, the macro environment, the level of reaction to the pandemic, and the condition of WFH might be different across the continent (e.g., Europe vs. Asia). Secondly, the characteristics (scope, maturity, types) of software engineering tasks might be differently defined and perceived across investigated locations. In any case, it seems that the geographical dimension introduces a boundary to any general strategy for communication, collaboration, coordination, management, and engineering activities during WFH situations.

5.2 | Threats to validity

We will discuss validity according to the four perspectives presented by Wohlin et al.,[63] complemented by survey-specific validity aspects.[64,65]

Construct validity concerns the relationship between a theory behind an investigation and its observation.[63] As the goal of the survey is to gain industrial insights on WFH and related practices, we do not aim at fully developing or validating hypotheses. However, the observations from our study can give hints for further research about the working environment (i.e., WFH) and different properties of software companies and software startups. To enhance the construct validity, we used validated scales for software engineering activities and project management. We are also confident about the confidentiality and anonymity of the respondents, hence reducing as much bias as possible.

Internal validity deals with the relationship between a treatment and its results.[63] We have a filtering question so that only respondents who experienced an impact on their work and their companies can answer questions. Our survey platform automatically collected log information, such as start date, completion time, and IP of the respondent. These data also helped us to filter poor-quality data.

An inherent threat to survey research is that surveys can only reflect respondents' perceptions rather than objective measurement. To some extent, we aim at revealing exactly those perceptions. To make the questions understood in the same ways by all respondents, we reviewed and revised them several times (Section 4.2). The survey versions were reviewed by people from representative countries to reduce the possible misunderstandings due to language or cultural differences. To mitigate the threat of perception bias, the survey was conducted anonymously and backed up (and further explored) by insights from qualitative data.

We implemented several approaches to making sure each participant can validly represent their team. The purpose and scope of the survey was explicitly stated in invitations to participation. So people can participate if they find the survey relevant and interesting to their experience. We had two screen questions in the beginning of the survey to filter the irrelevant participants. We assume that the respondents can reflect on his/ her own work and team. Respondents who do not work in a team (one-person team) are also excluded from the further process.

Our findings are based on a reasonable but still limited number of respondents. With 45 questions (including complex questions and open-text questions), our survey is among long questionnaires that are conducted in software engineering. It takes, in average 18 min 50 s to complete the survey. Two hundred ninety-seven valid data points is a large dataset when compared to other surveys in software engineering journals.[56,66–68]

External validity is concerned with the generalization of the conclusions.[63] We cannot make a generalized conclusion from our study. Proper sampling is very difficult to conduct due to no credible sampling frames (population lists) for the units of analysis in software engineering research.[20,69] Our unit of analysis is the software company, but we are not able to estimate representativeness of our population due to the unavailability of empirical data from each industry sector and each country. A different result might be observed with a different sample. However, the survey can be repeatedly conducted and new results can be synthesized with what is reported in this study. We note that it is seen as uncommon to have a survey on a narrow topic in software engineering with more than 100 valid responses.[67]

Also, the responses are not equally distributed over company types, team size or geographical locations. This probably has an influence on the distribution of responses. We have implemented several approaches to reduce this risk. We have conducted sensitivity analyses to identify any significant variations that might arise from combining responses from these smaller countries. t-test results do not reveal any significant differences across context factors. While we cannot generalise going beyond the contexts described and that we might even expect partially different results in different countries, we can in the future follow our design of this survey and further steer the continuous replications and syntheses of the results while capturing precisely the context to establish a more reliable and empirically solid theory.

Conclusion validity is concerned with obstacles to drawing correct conclusions from a study.[63] Although we did not conduct random sampling, we have tried our best to diversify the respondents regarding their geographical locations (from 35 countries), industrial sectors (more than 18 sectors), company types (startups and established companies) and team size. Conclusion validity is further strengthened by data triangulation, having consistent observations from both quantitative and qualitative data.

5.3 | Implications to practice

What does it mean to have WFH as a new work arrangement? Our study reveals an internal, spatial shift into fully remote work or a type of hybrid mode. For a company that wants to adopt WFH strategies, it is useful to be aware of a different set of tools and different coordination and control mechanisms. The consideration of the work arrangement, tools and associated control mechanisms should be integrated into one comprehensive strategy.

Are project managers impacted when their team switches to WFH? Project managers can be the most impacted role in a software team with extra work of coordination, communication and difficulties in team planning and maintaining their influence in the online matter. The negative impact can be observed in several scenarios, for instance, intensive reliance on external stakeholders or complicated task dependencies. A company that employs a project manager should be aware of such possible overload to have the necessary treatment or adjustment.

Are software engineers impacted when their work switches to WFH? There is no overall consensus answer to this question, as we find both negative and positive impacts. The majority reported a 'no impact' situation, which might imply that most people do not perceive WFH as a harmful situation. Companies who want to employ the strategy can find supportive arguments from our findings.

What is helpful when adopting WFH? We believe that software engineers that have experience in global software development (outsourcing, distributed teams, open-source software projects, etc.) will not be impacted by forced WFH situations. To prepare for engineers without such experience, an onboarding process (like in open source projects) will be helpful. Furthermore, the establishment of development processes that isolate and resolve the impacted areas (i.e., customer acceptance test) will be helpful in introducing WFH to a project.

Last but not least, we suggest that the WFH strategy should be assessed and defined in a specific context. There will be no one-size-fits-all solution for the switch to WFH. Even though we do not find evidence of the difference in software startups, at least the geographical areas matter. Other aspects, such as application domain, and national, organizational, and cultural dimensions, can be taken into account when defining a WFH strategy.

6 | CONCLUSIONS

In the near future, the working environment will have a significant impact in where, when and how WFH is adopted in software projects; hence it is important to understand its impact on teams and tasks besides productivity or well-being. This study reports results from a global-scale, cross-sectional survey on WFH and its impact on software project management and engineering. We collected answers from 297 respondents around the world. For future work, we have three different directions to explore. Firstly, we will explore the remaining surveyed topics, which are innovation and resilience. Secondly, we will perform more quantitative analysis, that is, factor analysis or regression analysis, to understand the possible relationship between characteristics of WFH arrangement, coordination practices, and perceived productivity. Thirdly, we can perform follow-up qualitative studies to explore in-depth observations initially found from this study.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this paper.

AUTHOR CONTRIBUTIONS

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DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article

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APPENDIX A

The list of survey questions is presented in Table A1 and the set of classification rules for company types is presented in Table A2.

TABLE A1 The full questionnaire.

Section	Questions	Type
Demographic information	How do you know about the survey?	MC
	Do you experience or observe an impact of COVID-19 to your work/ your company to any extent?	CE
	Do you work in a company that develops software-intensive products or provide software development services?	CE
	What type would you consider your company?	MC
	What is the last known state of the product/service created in the start-up?	MC
	What is the size of your team that you work?	MC
	How long has your company existed?	MC
	Select the most important sector that your company develops software for or serves?	MC
	In which city and country are your operations based?	OE
	What is your current role in your company?	MC
Working and collaboration practices	How would you describe the normal working practices among software developers in your company before COVID-19?	MC
	How would you describe the normal working practices among software developers in your company during COVID-19?	MC
	How would you describe your working situation due to COVID-19?	MC
	Which digital tools you are using now in your company for collaborative work and socializing ?	OE
	What are the new approaches used in your company to monitor and control the work due to COVID-19?	MC
	What coordination approach is used in your team due to COVID-19?	MC

(Continues)

TABLE A1 (Continued)

Section	Questions	Type
Software engineering	COVID-19 has an impact on the following requirement engineering activities?	LS5
	If one of your answers to requirement engineering questions is not neutral, can you explain the impact and why it happened?	OE
	COVID-19 has an impact on the following software architecture activities?	LS5
	If one of your answers to software architecture questions is not neutral, can you explain the impact and why it happened?	OE
	COVID-19 has an impact on user experience (UX) design activities	LS5
	If one of your answers to UX design questions is not neutral, can you explain the impact and why it happened?	OE
	COVID-19 has an impact on the following software implementation activities?	LS5
	If one of your answers to software implementation questions is not neutral, can you explain the impact and why it happened?	OE
	COVID-19 has an impact on the following software quality assurance activities	LS5
	If one of your answers to software quality assurance questions is not neutral, can you explain the impact and why it happened?	OE
	Due to COVID-19, the amount of time spending in the following activities?	LS5
Project management	It is more difficult to have an overview of who does what due to COVID-19?	LS5
	It is more difficult to plan for resources, time, risk, and milestones (or some of these items) due to COVID-19?	LS5
	COVID-19 has an impact on how your team/ company maintains the organizational culture or team spirit	LS5
	COVID-19 has an impact on how your team/company maintains or changes a leadership style for the current way of working	LS5
	COVID-19 has an impact on the current competence need in the team/ company?	LS5
	To what extent you have experienced a delay in your projects in general due to COVID-19?	LS5
Resilience and innovation	According to your experience, how are the following software engineering roles affected due to COVID-19?	LS5
	To what extent do you agree/ disagree with the following statement about the impact of COVID-19 to innovation?	LS5
	Can you elaborate further on some of your answers to the impact of COVID-19 on your company's innovation activities?	OE
	Which properties of your company makes it more resilient to the pandemic?	LS5
	Can you elaborate more on some of your answers to the factors contributing to your company's resilience?	OE
	There is a change in value generated to users/ customers due to COVID-19 in comparison to due to COVID-19	LS5
	How do you rate your work performance during COVID-19 in comparison to pre-COVID-19 time?	LS5
	How do you rate your company performance during COVID-19 in comparison to pre-COVID-19 time?	LS5
	What do you think about new & effective way of working emerge due to COVID-19 that will remain after COVID-19?	OE
	If you are available for a follow-up interview, please add your email address below	OE

TABLE A2 The classification rules for defining startups.

Company type	Last-known state of the main product	Status (classified)
Established	Not applicable	Established
Established	Other	Established
Established	Product is rather stable, the focus is on gaining customer base.	Established
Established	Product is stable, market size, share and growth rate are established. Focus is set on launching new variations of the product.	Established
Established	Product was released to the market and is actively developed further with customer input.	Established
Established	A product prototype is developed and has not yet been released to market.	Startup
Startup	A product prototype is developed and has not yet been released to market.	Startup
Startup	Not applicable	Startup
Startup	Other	Startup
Startup	Product is rather stable, the focus is on gaining customer base.	Startup
Startup	Product is stable, market size, share and growth rate are established. Focus is set on launching new variations of the product.	Established
Startup	Product was released to the market and is actively developed further with customer input.	Startup
Not sure	A product prototype is developed and has not yet been released to market.	Startup
Not sure	Not applicable	Unknown
Not sure	Other	Unknown
Not sure	Product is rather stable, the focus is on gaining customer base.	Established
Not sure	Product is stable, market size, share and growth rate are established. Focus is set on launching new variations of the product.	Established
Not sure	Product was released to the market and is actively developed further with customer input.	Startup