CO-DESIGNING PLANNING SUPPORT TOOLS FOR STAKEHOLDER ENGAGEMENT IN COLLABORATIVE SPATIAL PLANNING PROCESSES

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CO-DESIGNING PLANNING SUPPORT TOOLS FOR STAKEHOLDER ENGAGEMENT IN COLLABORATIVE SPATIAL PLANNING PROCESSES

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To my loved children Gerardo and Rosalba,
and my nieces and nephews,
for whom I want to be a hero.

Wisdom will protect you just like money;
knowledge with good sense will lead you to life.

Ecclesiastes 7:12. Contemporary English Version.

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1. Introduction

1.1. Motivation

Collaborative spatial planning refers to activities where stakeholders with different knowledge, values, interests, and roles work cooperatively to frame or address a spatial planning problem of common concern (Lin & Geertman, 2015). These problems concern, for instance, the use of land and supporting infrastructure and facilities and their environmental and social impact (González, Kelly, & Rymszewicz, 2020; Nuissl & Heinrichs, 2011). Spatial planning problems vary in complexity, degree of structuration, and geographic scope (Georgiadou & Reckien, 2018). Many of them can be characterised as "wicked" or ill-defined problems as they are usually interconnected with other problems (Lundström, Raisio, Vartiainen, & Lindell, 2016); different people are affected; and, there is uncertainty on the origin of the problem, the possible solutions, values of and acceptance by beneficiaries (Flacke & de Boer, 2017; Goodspeed, 2015; Panagiotopoulou & Stratigea, 2017).

Geoinformation (GI) tools can be used to address spatial planning problems in different ways, e.g., as a problem solver, problem mediator or problem recogniser, depending on the problem's wickedness (Georgiadou & Reckien, 2018). In the first case, GI tools are utilised to provide solutions to structured problems with certain causes and effects; in the second case, GI tools can provide a platform to address stakeholder participation and geoinformation analysis in semi-structured problems; in the third case, GI tools can be utilised to explore the uncertain causes and effects of 'wicked' or unstructured problems. In particular, GI based planning support systems (PSS) that offer interactive map visualisation and analytical capabilities aim to contribute in two ways: they may help improve the social interaction during the process, e.g., more inclusive or more interactive, or improve the outcome of the process, e.g., more suitable plans (Newton & Glackin, 2013; te Brömmelstroet, 2013). To do so, PSS utilise maps as means for learning, information exchange, discussion, analysis and decision making (Rambaldi, Kyem, McCall, & Weiner, 2006). We can distinguish three main categories of PSS, namely informing PSS, communicating PSS and analysing PSS (Vonk, 2006). Informing PSS intends to make the planning related information and knowledge accessible and understandable for users; communicating PSS focuses on facilitating communication and discussion among stakeholders, and analysing PSS aims to assist in discovering insights, scenario modelling, analysis and evaluation and design and assessment of alternatives.

Despite the availability and proven potential of planning support (PS) tools, they have not been fully adopted in planning practice (González et al., 2020; Page et al., 2020; Rittenbruch et al., 2021; Russo, Lanzilotti, Costabile, & Pettit, 2018a; te Brömmelstroet, 2017b); their application is limited to the specific project scope they are developed for (Pelzer, 2015). This problem is known as the "implementation gap" (Vonk, 2006) and has been attained partly to the PS tools' poor usability, e.g., due to complexity, low user-friendliness and steep learning curve (Geertman, 2017; Russo, Lanzilotti, Costabile, & Pettit, 2018b). To address this problem, previous research suggested the development of PS tools in close cooperation with users, e.g., by following human-centred design principles; understanding the value of PS tools from the practitioner perspective, and examining the application context of successful cases of PS tools implementation (Geertman, 2017; Pelzer, Geertman, Van Der Heijden, & Rouwette, 2014; Russo et al., 2018a). Nonetheless, while considerable attention has been paid to explaining the implementation gap, there is scant attention to potential solutions to bridge it (Geertman, 2017; Punt, Geertman, Afrooz, Witte, & Pettit, 2020; te Brömmelstroet, 2017b).

The use of maptables for stakeholder engagement in planning processes is a relatively recent approach of a communicating PSS that is gradually becoming a key instrument in planning workshops, as suggested in several studies (Geertman & Stillwell, 2020; Pelzer, Arciniegas, Geertman, & De Kroes, 2013; Pettit et al., 2020; Shrestha, Flacke, Martinez, & van Maarseveen, 2018). Maptables are large touch screen devices that provide an interactive geospatial platform suited for collaborative group work, including laypersons (Heijne et al., 2018; Pelzer, Goodspeed, & te Brömmelstroet, 2015). They support stakeholders' communication and consensus building (Flacke & de Boer, 2017; Janssen & Dias, 2017) and enable more equitable participation due to their horizontal orientation that accommodates stakeholders around the content, enabling them to participate in the discussion. However, current PS tools designed to exploit maptables capabilities such as the large display and touch-responsive are scarce or have shortcomings, i.e., usability or functionality issues (Punt et al., 2020). Also, there is a gap between what PS tools offer and what users need (Hewitt & Macleod, 2017), meaning that, in general, PS tools are often more advanced than required in practice (Geertman, 2017).

Recently, co-designing approaches have been gaining momentum in planning (Rittenbruch et al., 2021). In the literature, we can encounter different approaches with varying levels of user involvement (Bont, de, Ouden, den, Schifferstein, Smulders, & Voort, van der, 2013; Heijne et al., 2018). Nonetheless, most of the studies refer to the co-design of the 'solution' to the planning issue (Heijne et al., 2018) or the co-design of a PS tool for a particular project using existing software solutions, i.e., the co-design of the process or information (González et al., 2020; te Brömmelstroet & Schrijnen, 2010). Few studies have addressed the development of PS tools in close cooperation with users (Pettit et al., 2020; Rittenbruch et al., 2021; Trubka, Glackin, Lade, & Pettit, 2016), and too little attention has been paid to the particular case of maptables. Specifically, studies on the co-design of open and tailored applications to tackle a spatial planning problem when these devices are used as PSS are scarce.
The point of departure of this research is that maptables have the potential to foster stakeholders' engagement in collaborative spatial planning processes. This dissertation aims to contribute to the PS tool design and development discussion by focusing on close interaction with the intended users while developing PS tools. The following sections introduce the key concepts of the study and describe the research problem, research objectives and research questions. It then turns to an overview of the methods, and lastly, the outline of the dissertation is presented.

1.2. Key concepts

1.2.1. Collaborative spatial planning/stakeholder participation

Collaborative planning, also referred to as participatory planning, implies a conscious effort of stakeholders to work cooperatively and frame a problem while a shared understanding is established, modified, or maintained (Maceachren & Brewer, 2004). Such stakeholders are individuals, groups, public or private organizations, and institutions (Georgiadou & Reckien, 2018) with a stake, concern, or interest about the issue in consideration that can be affected by, or can influence, the decision-making process that is being performed on this (Gueze & Jonker, 2013). However, reaching a shared understanding is challenging as decisions are usually contentious, and interaction between stakeholders varies from agreement and contestation (Maceachren & Brewer, 2004; Pfeffer et al., 2013). Moreover, collaborative planning is seen as good governance practice that supports participation, accountability and promotes transparency while improving acceptance and commitment to implement the decision (Lin & Geertman, 2015; McCall & Dunn, 2012; Slager et al., 2007). Furthermore, stakeholders' participation is embedded in planning legislations in several countries and particular contexts (EU, 2002; Hordijk, Sara, Sutherland, & Scott, 2015; Staffans, Kahila-Tani, Geertman, Sillanpää, & Horelli, 2020; Warren-Kretzschmar & Von Haaren, 2014). Nonetheless, it is not generally prescribed how to involve such stakeholders, and their level of involvement in a planning process can range from information receptors to active actors able to initiate actions independently (Heijne et al., 2018; Mostert, 2003). In this spectrum, collaboration implies a high level of stakeholders' involvement in the planning process, including designing alternatives and identifying the preferred one (Heijne et al., 2018).

Instead of sketching a final plan, collaborative planning focuses on engaging the various stakeholders in a process where they can interact and communicate on an equal basis to reach consensus, social learning, and mutual understanding while addressing a common problem (Pelzer, Arciniegas, Geertman, & de Kroes, 2013; Stratigea, Papadopoulou, & Panagiotopoulou, 2015). Stakeholders opinions, wishes, and local knowledge at the early stages of a participatory planning process also feed its subsequent stages (Pfeffer et al., 2013).

This research focuses on collaborative spatial planning processes in which (digital) GI tools are used as mediators for social interaction between stakeholders in addressing spatial planning problems. Therefore, utilisation of geographic information is a backbone of the framing problem process.

1.2.2. Geoinformation (GI) tools and maptables

With the communicative turn in planning, enabling participation is a topic of growing interest among scientists and policymakers (Pettit et al., 2015, Stratigea et al., 2015); for example, to ensure that information is well-understood by non-experts and that all voices are heard (Mietlicki et al., 2020; Pan & Deal, 2020; Riedel et al., 2017). GI tools are being increasingly used in this regard. Nonetheless, the capabilities of such technologies should be carefully examined to facilitate rather than impede the dialogue among stakeholders during a collaborative process (McCall & Dunn, 2012; McEvoy, van de Ven, Blind, & Slinger, 2018).

There is a wide variety of GI tools, such as GIS, PSS and online geo-applications, among others, that can be included in a participatory process (Panagiotopoulou & Stratigea, 2017; Pfeffer, Martinez, Baud, & Sridharan, 2011) depending on a) the purpose of the participation; b) the planning process phase; c) participation level aimed at, e.g., information, consultation, among others; and d) setting, e.g., remote or co-located. Communicating PSS, in particular, are often used in traditional planning workshops as they enable users to collectively analyse scenarios, raise awareness regarding a particular issue or gather information, e.g., local knowledge or preferences (Akbar, Flacke, Martinez, Aguilar, & van Maarseveen, 2020; Flacke, Boer, de van den Bosch, & Pfeffer, 2020) . Such planning workshops are structured meetings where various stakeholders collaborate in the context of policy-making, planning interventions designs or problem awareness raising (Condon, Cavens, & Miller, 2008; Pelzer, Goodspeed, et al., 2015).

A maptable is a particular case of a communicating PSS (Pelzer et al., 2014; Staffans et al., 2020) when coupled with spatial data, information, and models. It provides a shared space for synchronous collaboration (co-located) (Isenberg et al., 2012) by accommodating direct verbal and non-verbal communication between participants while the discussion stays focused on the spatial content presented in the display (Scott et al., 2010). Maptables positively influence the group dynamic by accommodating an enhanced interaction among stakeholders and favouring a more equitable participation process because their horizontal orientation facilitates that all participants can contribute to the discussion (Flacke, Boer, de van den Bosch, & Pfeffer, 2020; Pelzer et al., 2014; Rogers & Lindley, 2004). Usually, the central goal of using maptables in planning workshops is to facilitate the interactive discussion through visualisation and immediate feedback on alternative designs (Geertman & Stillwell, 2020). This implies that the production of an improved outcome, e.g., a better plan, due to the analytical function of the PS tool has become less prominent (Flacke & de Boer, 2017; Pelzer, Arciniegas, Geertman, & de Kroes, 2013; Shrestha et al., 2018).

The literature reports on several topics addressed with maptables, including rural and urban planning, sustainable redevelopment, urban health, energy transition, and climate change, among others. In most cases, PS tools were implemented in desktop and proprietary software, often not optimized for these devices (Flacke, Shrestha, & Aguilar, 2019; Punt et al., 2020). As maptables (i.e., the hardware) are increasingly available nowadays (Pelzer et al., 2014; Rittenbruch et al., 2021; Runck, 2017; van der Laan, Kellet, & Girling, 2013) and progressively adopted in professional environments to support collaborative planning and decision making processes, particularly when stakeholders have divergent opinions (Geertman, 2017), the scarcity of open-source tool deserves research attention.

1.2.3. User requirements for planning support tools

User requirements for software is a set of needs expressed by its users or stakeholders considering some constraints in which such a tool must function (Soares, Vrancken, & Verbraeck, 2011). The process of eliciting, analysing, documenting and managing user requirements is called requirement engineering and is a typical phase of software tools development. Its purpose is to develop, later on, software based on the gathered user requirements (Soares et al., 2011). Nonetheless, understanding and managing user requirements is a significant challenge (Hewitt & Macleod, 2017). In this regard, the mismatch between the offer and user requirement of PS tools has been documented in the literature. For example, Geertman (2017) emphasizes the need for straightforward instruments rather than over-complicated ones often supplied by developers. Hewitt et. al (2018) also reviewed the main requirements that PS tool users do have and Russo et al. (2018a) remarked on the mismatch between user requirements and what PS tools offer. This suggests that PS development has failed in providing tools that do meet user needs, perhaps due to the difficulty of "hard sciences", e.g., informatics, in engaging with social science related topics (Pan, Geertman, & Deal, 2020).

Scholars have provided a vast list of potential requirements for planning practice, including advanced visualisation, free-hand sketching, spatial analysis, cloud computation, and, more recently machine learning capabilities (Rittenbruch et al., 2021; Vonk & Ligtenberg, 2010; Voskamp & Van de Ven, 2014). Nonetheless, most requirements are envisioned by researchers and disconnected from planning practice (González et al., 2020; Hewitt & Macleod, 2017; Sun & Li, 2016). Also, multiple tools are often required to support a particular planning process (Palomino, Muellerklein, & Kelly, 2017), and not all

spatial planning problems can be addressed utilizing a PSS (Geertman, 2017). Therefore, understanding the need for a PSS and the user requirements is crucial. However, detailed studies reporting on user requirement engineering applied to PS development deserve more attention (Punt et al., 2020).
User requirements elicitation and validation is a major challenge in software development in general. The particularities of planning processes add complexity to such endeavour because a PS tool interface, mainly based on maps and images, should address usability from the human-computer interaction (HCI) point of view but also usefulness from the planning perspective (Pan et al., 2020; Sluter, van Elzakker, & Ivánová, 2017). Recent trends in PSS tool development indicate that involving users in a dialogue with PSS developers, e.g., via human-centred design or agile principles, might bridge the mentioned mismatch between what is offered by researchers and what planning practice needs (Pettit et al., 2020, Punt et al., 2020).

1.2.4. User involvement in planning support tools development

Involving users in a design process is beneficial because this might reveal user needs (Bont, de et al., 2013) and promotes acceptance of the product being designed, e.g., an interactive PS tool, and a smooth implementation phase later on (Vonk & Ligtenberg, 2010). This practice has been widely adopted in product design (Bont, de et al., 2013) but is still lagging in PS tool development (Hewitt & Macleod, 2017; Russo et al., 2018b; Yap, Janssen, & Biljecki, 2022). Users can be involved at different levels of collaboration and different design phases. Users can provide information and feedback while testing concepts or being more actively involved, e.g., by providing advice and recommendations (Bont, de et al., 2013; Heijne et al., 2018); co-design is a higher level of user involvement.
Co-design of PS tools is gaining traction in the literature (Rittenbruch et al., 2021), meaning users and stakeholders are increasingly involved in developing PS tools. Studies reported in the literature suggest two central directions of user involvement in PS tool co-design, namely a) concerning the underlying PS spatial model and b) related to the PS tool (i.e. software). The first direction implies data provision, feedback about data and model parameters, scenarios and output. For example, Page et al. (2020) described users' participation in the adaptation of LEAM, an open-source PSS, to predict how land use would

evolve under given conditions. Users and PSS developers engaged in an iterative process to generate such an adapted LEAM's version; it comprised adjusting data and parameters of the LEAM's model. Te Brömmelstroet & Schrijnen (2010) followed a similar approach to adapt a transportation model into a land-use and transport PSS. The second direction means testing software prototypes and providing feedback about them, e.g., their functionality and graphical user interface - GUI. For example, Vonk & Ligtenberg (2010) cooperated with intended users to redesign a sketch tool with a socio-technical approach; the resulting tool was better accepted than the original tool that was developed following a traditional development method. In another study, Trubka et al. (2016) utilised Agile and co-design methods to develop a tool for neighbourhood geodesign, visualisation, and assessment. The iterative process included gathering user feedback about the prototype and associated refinements based on the feedback. Recently, Pettit et al., (2020) involved users in a co-design process to produce RAISE, a PS toolkit for planners and policy-makers to explore land value uplift due to new train stations. The iterative co-design process, aimed at ensuring usability and usefulness, included six workshops to address data inputs, model parameters, scenarios, software functionality and UI. End-users provided positive feedback during workshops. However, a comprehensive end-user evaluation was not reported as the toolkit was still at the early stages of development.

In this research, co-design is understood as the cooperative work between non-expert users and design experts during the design and development process of a geospatial interactive PS tool (Sanders & Stappers, 2008). This cooperation means providing information about the context of use, e.g., conditions and tasks, and feedback during prototype evaluation (Bont, de et al., 2013). We focus on combining two main approaches of user involvement, namely Agile software development and human-centred design (HCD). Agile techniques are widely adopted in software development and aim to address rapid software development, whereas HCD has been recommended to overcome usability issues of PS tools (Russo et al., 2018b). Nonetheless, there is a paucity of studies, in particular for maptables, that systematically address this (Flacke et al., 2020).

1.3. Research problem

Maptable-based PS tools are utilised to engage stakeholders in planning processes because they facilitate a spatial language and facilitate continuous dialogue among the stakeholders around it (Pelzer et al., 2014). In other words, maptables enable knowledge co-construction and a shared understanding of the problem at stake by triggering communication and collaboration between actors involved in the planning process (Pelzer, Geertman, & Van Der Heijden, 2015; Shrestha, Köckler, Flacke, Martinez, & van Maarseveen, 2017). Such engagement and collaboration are crucial when tackling (wicked) planning problems.

Although maptables have been increasingly used in collaborative planning, surprisingly, the software available, especially developed for these devices, is scarce or presents issues concerning usability and functionality. For example, interactive software suited for maptables such as Phoenix, lacks advanced spatial analysis capabilities, whereas other more advanced tools are designed for experts that can handle the technology, which impedes participation and collaboration of non-experts (Dias, Linde, Rafiee, Koomen, & Scholten, 2013; Jones & Maquil, 2015). In addition, common GIS software does not adapt well to touch interfaces (Punt et al., 2020) because they are designed for single desktop computers meaning single-user roots user interface (UI) that do not exploit the touch capabilities of maptables (Maceachren & Brewer, 2004; Vishkaie & Levy, 2012). Furthermore, there is hardly any open-source software tool available (Hewitt & Macleod, 2017; Pettit et al., 2020) that could effectively contribute to the uptake of PS tools in real practice. For example, RAISE, a system for land value and scenario planning that was recently co-designed with users and built on an open cloud-based architecture, is not available as a free and open-source project (Pettit et al., 2020). Also, as mentioned above, previous studies pointed toward developing PS tools in close cooperation with users as a mechanism to bridge the implementation gap (Russo et al., 2018b); this approach, however, is seldom reported in the literature (Pettit et al., 2014; Pettit et al., 2020; Vonk & Ligtenberg, 2010). For these reasons, our research was centred on developing an open and interactive PS tool for maptables that is usable and useful and could be potentially adopted in planning practice. In doing so, we explored how users can be engaged in the design and development process that leads to such a tool.

1.4. Research objectives and research questions

The main objective of this research is to conceptualise, design and implement an interactive, open-source PS tool for maptables that fosters stakeholder interaction and engagement in collaborative spatial planning processes in close cooperation with users. To achieve this objective, specific objectives and research questions were formulated as follows:

1. To conceptualise, with its intended users, a PS tool for stakeholders' engagement in collaborative planning processes.
   - What are the general user requirements of different actors, e.g., planning practitioners, GIS expert users and laypersons that need to be addressed by such a PS tool?
   - How does the conceptual PS tool for collaborative planning look?

2. To design and develop a PS tool for stakeholder engagement in collaborative planning processes in collaboration with its intended users
   - What is a suitable application platform to accommodate a basic version of the conceptualised tool?
   - How to incorporate intended users into the design and development process?

3. To implement a PS tool and evaluate its usability and usefulness during spatial planning processes in two case studies.
   - What are the specific user requirements of the PS tool for the given context of use, i.e., problem domain, planning process addressed and intended users?
   - To what extent is the developed and implemented tool usable and useful in the given context of use?

1.5. Research approach

This research approach, illustrated in Figure 1-1, consisted of two main components: the conceptualization of a PS tool and its design, development and implementation (application and evaluation) for two different case studies (contexts of use). To address the conceptualisation we applied common methods for requirement elicitation, such as a state-of-the-art literature review, user interviews and user stories (Brhel, Meth, Maedche, & Werder, 2015; Pretorius, Hobbs, & Fenn, 2015; Sluter et al., 2017). To design and develop the conceptualized tool, we combined HCD and Agile software development techniques in two different case studies; the first in Sumatra, Indonesia and the second in Bochum, Germany. There was a need for an interactive tool and access to the stakeholders involved in the planning processes in both cases. The evaluation of the developed tool concerned its usability and usefulness as perceived by users. Self-reported post-workshop questionnaires were used to this end.

The analysis of state-of-the-art literature provided potential user requirements and shortcomings of current PS applications. We explored the validity of such requirements and elicited new ones through semi-structured interviews with representatives of identified user groups, namely planning practitioners, planning researchers, GIS experts and laypersons previously involved in collaborative planning processes with maptables. Summaries of those interviews were utilised to express the requirements in user stories. We then clustered those stories and drew up a conceptualization identifying the core building blocks of the digital PS tool for maptables.

By combining HCD with Agile methods during the PS tool development, we addressed both usability and rapid software development (Jurca, Hellmann, & Maurer, 2014; Sfetsos, Angelis, Stamelos, & Raptis, 2016). HCD emphasizes the interface design process, whereas Agile methods for development are focused on functionality. Such combination of HCD and Agile has not been closely examined in the context of PS tool development (Flacke, Shrestha, & Aguilar, 2020).

The human-centred design (HCD), previously known as user-centred design (UCD) is an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (ISO 9241-210, 2019, pp. 2). To achieve this goal, HCD relies on close interaction with users through continuous iterations from understanding and specifying the context of use until the produced design meets the specified requirements. A HCD approach was selected because previous studies suggested it for user acceptance of PS tools; nonetheless, little attention has been paid to this direction (Russo et al., 2018b).

Agile techniques focus on developing working code iteratively instead of extensively documenting and planning the entire software development processes ("Manifesto for Agile Software Development," 2001). User requirements and solutions evolve through the dialogue and collaborative effort of the developer team and the intended users and stakeholders of the tool - software. Agile approaches are based on a) iterative and small incremental development work, b) efficient face-to-face communication, c) short cycles (to provide feedback and adaptation of goals) and d) focus on quality. Agile principles have been widely adopted in software development because they provide for flexible approaches to delivering rapid solutions in short iterations while fostering close collaboration among developers and users, and stakeholders of the software (Ardito, Baldassarre, Caivano, & Lanzilotti, 2017a; Brhel et al., 2015). Therefore, an Agile approach was selected for the current research.

Applying the tool involved preparing the required dataset for each case study, structuring the maptables-based workshops, i.e., participants' tasks, and conducting those workshops that were moderated by expert planners. Next to developing and applying the tool, we examined its usability and usefulness. In this study, usability is understood as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (European Committee for Standardization, 2018 p. 2). In contrast, usefulness refers to the added value of utilizing the developed PS tool (Pelzer et al., 2014) during spatial planning workshops with maptables.

Usability of PS tools was reported as an important factor preventing the uptake of these instruments (te Brömmelstroet & Schrijnen, 2010; Vonk, Geertman, & Schot, 2005). To overcome this issue, Russo (2018b) recommended improving the overall experience of planner practitioners by enhancing usability, which then hopefully fosters user engagement and satisfaction. However, the literature regarding systematic usability evaluations of PS tools is still scarce or follows different directions, for example, by considering different dimensions or elements of the PS tool and the planning process (Ardito, Buono, Caivano, Costabile, & Lanzilotti, 2014; te Brömmelstroet, 2013). Moreover, usability evaluation was proposed in the early 90ies, but its adoption remains low among developers (Russo et al., 2018b). In this research, usability evaluation concerned the tasks users perform, e.g., map navigation, drawing, text input or queries, with the PS tool during a maptable-based workshop and their self-reported perception of effectiveness, efficiency and satisfaction in doing them. Prior to a usability evaluation with the real users of the tool, an evaluation in controlled conditions was conducted, i.e., workshop pilots. The purpose of such pilots was to test the questionnaire's clarity and whether the user tasks' were doable.

The usefulness of PS tools and the link between perceived usability and perceived usefulness have also been investigated by scholars (Jiang, Geertman, & Witte, 2020; Pan et al., 2020; Pelzer, 2017; te Brömmelstroet, 2017a). In this regard, different dimensions of usefulness were identified, i.e., benefits of applying a PS tool at individual, group and outcome levels (Champlin, te Brömmelstroet, & Pelzer, 2019; Pelzer et al., 2014). The first refers to the benefits for an individual, whereas the second means the advantages for the group when using a PS tool. The outcome level refers to the improvement gained concerning the goal of the planning process. As this research focuses on PS tools for mediating communication and collaboration, the usefulness of PS tools is explored at the individual and group levels as perceived by users.

The outcome of the PS tool evaluation was analysed and, when applicable, fed another iteration of the design and development cycle.

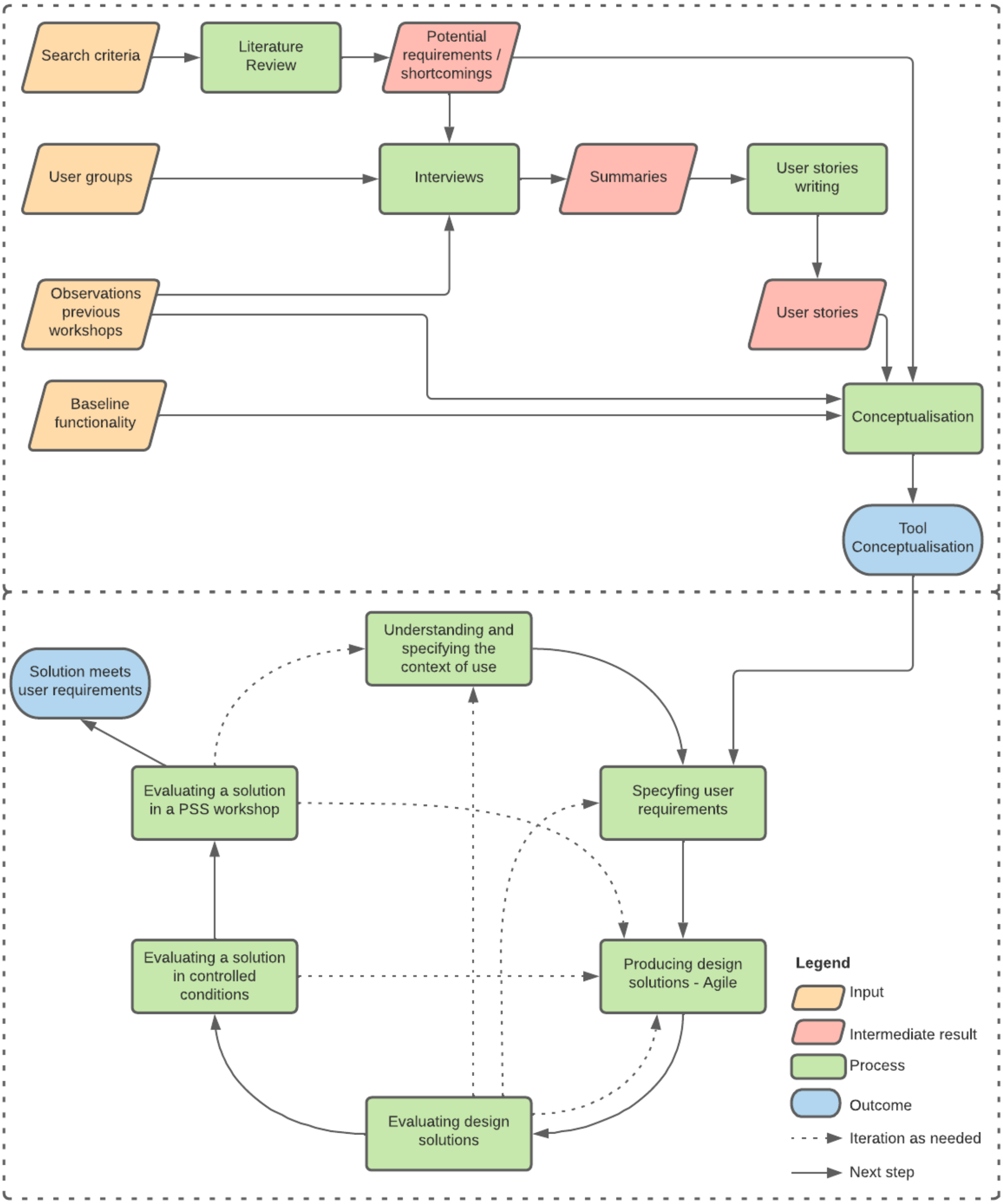

Figure 1-1. Methods overview.

The lower part of the diagram, which concerns the design, development, application and evaluation of the PS tool, was executed two times in the two different case studies mentioned above. These studies, reported in chapters three and four, involved different contexts and stakeholders.
The outcome of this research includes three research articles and a functional open-source tool. These three articles of which two are published, and one is in review for publication are included in this manuscript. Technical details of the PS tool are given in Chapter 5. The following section provides an overview of the structure of this thesis.

1.6. Thesis Outline

This dissertation comprises six chapters, including this introduction as Chapter one. Chapters two to four present the main findings as published or in review by scientific journals. Chapter five describes the developed PS tool, and chapter six presents the research synthesis.

Chapter one presents the background concepts, identified research gap, objectives and questions. It also gives an overview of the methods utilised in this research.

Chapter two describes the conceptualization of a digital interactive tool to support collaborative spatial planning processes using a maptable. Three central building blocks for such a tool were identified to offer support concerning mapping, analysis, and space-time settings. Intended users of the tools were involved in the conceptualisation process that provided the basis for its subsequent development.

Chapter three focuses on developing an Open Geospatial Interactive Tool, OGITO, in close collaboration with users utilizing a combination of Agile and Human-Centred Design methods. OGITO was evaluated in two villages in Sumatra, Indonesia, in the context of a participatory process called Musrenbang. The main findings showed the added value of iterative development and user feedback to address the tool’s usability and functionality.

Chapter four describes the co-design and development process that led to OGITO-noise, an **O**pen **G**eospatial **I**nteractive **TO**ol to support noise action planning. This chapter emphasizes the active role of users in the iterative design, development and usability and usefulness evaluation of the tool. Hybrid methods combined online co-design meetings and face-to-face evaluation. The case study was located in Bochum, Germany. Users evaluated OGITO's usability as positive, also expressing the intention to use it in the near future.

Chapter five describes technical aspects concerning OGITO's architecture, front-end components and services, and specifications of the back-end, i.e., servers and database. This chapter also reflects on the choices made during OGITO's development and recommendations for future versions of the tool.

Chapter six summarizes the results and presents the answers to the research questions. This chapter also reports on this study's main contributions and limitations and outlines recommendations for future work. It finalises with a reflection on the PhD research journey.

The PhD research compiled in this dissertation was not a one-person effort. It required expert advice and the collaboration of several professionals, particularly for its interdisciplinary approach. The author acknowledges this by using we in the text. Nonetheless, the author is the leading researcher, and, therefore, the content of this manuscript presents the author's ideas and thoughts.

2. Towards Supporting Collaborative Spatial Planning: Conceptualization of a Maptable Tool through User Stories *

* This chapter is based on: Aguilar, R., Flacke, J., & Pfeffer, K. (2020). Towards Supporting Collaborative Spatial Planning : Conceptualization of a Maptable Tool through User Stories. International Journal of Geo-Information, 9(29). https://doi.org/doi:10.3390/ijgi9010029

Abstract

Geographic information-based planning support tools implemented in a maptable have the potential to mediate collaborative spatial planning processes. However, available tools for a maptable either lack advanced analytical functions or have usability shortcomings. Given these limitations, this research aims to conceptualize an interactive planning support tool intended to fully exploit maptable capabilities while providing spatial analytical functions to better support planning and decision-making processes with a larger group of participants. To do so, we conducted a literature review of reported maptable-based applications and semi-structured interviews with identified intended user groups of such applications, and derived Agile user stories. We identified a) principal spatial analyses, b) must-have functionalities, c) required support for individual contributions, and d) preferred space-time settings for group work collaboration, and based on that, conceptualized an interactive tool for a maptable. By involving the intended users in the conception of the tool we revealed a discrepancy between the understanding of scholars and developers with respect to what users need and what they do. Intended user groups require tailored but straightforward instruments, rather than complicated or time-consuming models. Our research has laid down the foundation for future maptable tool development to support collaborative planning processes.

2.1. Introduction

Geographic information (GI) based planning support tools which offer interactive map visualization and analytical capabilities have the potential to mediate collaborative spatial planning processes. The shift from rational planning to communicative planning has promoted the utilization of such (digital) geo-tools as mediators for social interaction in addressing spatial planning problems (Foth, Bajracharya, Brown, & Hearn, 2009; Lin & Geertman, 2015; Pelzer et al., 2014; te Brömmelstroet & Schrijnen, 2010). However, planning practitioners have not fully incorporated Planning Support Systems (PSS) in their practice despite the variety of such tools developed to aid spatial planning tasks (Falco & Kleinhans, 2018; Geertman, 2017). This problem, known as "the implementation gap" (Hewitt & Macleod, 2017; Pelzer et al., 2014; Pettit et al., 2017; Russo et al., 2018b), is explained by certain characteristics of PSS such as low usability, vast requirements of expert knowledge or user unawareness of the PSS potentials (te Brömmelstroet & Schrijnen, 2010; Vonk et al., 2005).

A maptable is a PSS tool to support collaborative spatial planning processes usually arranged in a PSS workshop (Eikelboom & Janssen, 2017; Lenferink, Arciniegas, Samsura, & Carton, 2016; Pelzer et al., 2014). The primary characteristic of a maptable is the utilization of a large horizontal touch table that allows interacting with geospatial content. A maptable facilitates the communication process by providing a GI-based visual platform easy to understand by the majority of users regardless of their IT literacy or knowledge background (Warren-Kretzschmar & Von Haaren, 2014). Besides, the physical characteristics of the platform, its size, and horizontal orientation enable more equitable participation as all members are located around the content being able to contribute to the discussion (Rogers & Lindley, 2004). The enhanced interaction provided by a maptable might lead towards social learning, knowledge sharing, knowledge integration or consensus-building (Alexander et al., 2012; Shrestha et al., 2017; Voskamp & Van de Ven, 2014). Maptables have been applied in different fields, among others, energy transition (Flacke & de Boer, 2017), proposals for green and blue infrastructure (Voskamp & Van de Ven, 2014) or development of long term adaptation strategy in peatlands (Janssen, Eikelboom, Verhoeven, & Brouns, 2014).

Regardless of the proven and claimed benefits of a maptable, such as an enhanced interaction among different types of stakeholders or an improved negotiation led by the interactive feedback on measures being discussed (Pelzer, Arciniegas, Geertman, & Lenferink, 2015), three principal factors constrain the use of a maptable in a PSS workshop. First, there are limited software applications specifically designed for a maptable (Flacke et al., 2019). Moreover, typical applications reported in the literature have usability shortcomings that prevent users from achieving a satisfactory user experience because they have single-user roots meaning that those applications were designed for a desktop computer (Hewitt & Macleod, 2017). Second, a maptable can only accommodate a limited number of people in a PSS workshop. A typical maptable can host four to six participants at the maximum. Third, so far, a maptable PSS is only applied in a co-located and synchronous setting for group work collaboration (Flacke et al., 2019). However, certain collaborative spatial planning processes may require the contribution of participants in a different group work setting, e.g., people remotely located and not able to participate in a specific place at a specific time, or a larger audience that cannot be easily accommodated in a room.

Given the mentioned shortcomings, this research aims to conceptualize an interactive PSS tool for maptables specifically intended to fully exploit maptable capabilities while providing spatial analytical functions to better support planning and decision-making processes with a larger group of participants. To do so, we applied a combination of methods, namely a literature review of reported maptable-based applications, semi-structured interviews with identified intended user groups of those applications and Agile user stories. The interviews with intended users and their user stories served to involve expectations of intended users at the conceptualization—i.e., primary stage—of the development project of our tool.

2.2. Background

In this section, we elaborate on maptable-based PSS workshops to enlighten the organizational, technical, and physical aspects that should be considered when designing an interactive tool to support such a collaborative activity. Besides, we briefly illustrate the different space-time settings where collaborative planning processes can occur and the digital support they might require.

Moreover, we introduce human-centred design (HCD) and Agile user stories since we aim to conceptualize a PSS tool to be used in a maptable based on user needs.

2.2.1. A Maptable-Based PSS Workshop/Process

We define, based on the literature and our own expertise, a maptable-based PSS workshop as a structured meeting that provides a physical space and maptable(s) as a primary digital supporting tool(s) to facilitate the interaction among participants during collaborative, participatory processes (Arciniegas & Janssen, 2012; Flacke & de Boer, 2017; Pelzer, Goodspeed, et al., 2015). A maptable-based PSS workshop has three fundamental elements, namely (a) the planning problem context, (b) the purpose or intended outcome of the PSS workshop, and (c) the planning phase in which the workshop takes place (see Figure 2-1). The planning problem context involves the nature of the planning problem, stakeholders, and their setting concerning space and time. The planning problem refers to the issue being discussed, for instance, matters related to the use of land, infrastructure development, or facilities allocation (Nuissl & Heinrichs, 2011). The nature of the problem comprises its complexity, degree of structuration (Georgiadou & Reckien, 2018; Jones, 2011), and geographic scope. It defines the stakeholders to be involved—i.e., the individuals, groups, public or private organizations, and institutions that may have a stake in the problem (Gueze & Jonker, 2013)—and their characteristics such as knowledge, skills, experience, education, habits or preferences, geographic distribution, and time for participation (Isenberg et al., 2011). The purpose refers to the intended outcome of the workshop (Pelzer, Goodspeed, et al., 2015), meaning what is expected to be achieved from the stakeholder participation, e.g., design of proposals, consensus-building concerning the allocation of resources or learning about a particular problem (Alexander et al., 2012; Flacke & de Boer, 2017; Janssen et al., 2014; Nagel et al., 2014). The planning phase and the purpose delineate the orientation of the PSS workshop toward a communicational or an analytical emphasis and the tasks that participants are expected to complete. Lastly, the planning phase (Simon, 1960) plays a vital role in the purpose for which the application is used. For example, in an exploratory phase, more social interaction and communication to frame the problem than to develop concrete plans may be expected. This communication process could be supported by map-based visualization. In other planning phases, such as the design or choice phase, specific discussions which require not only map-based visualization but also analytical support such as impact analysis may be needed (Pelzer, Geertman, et al., 2015).

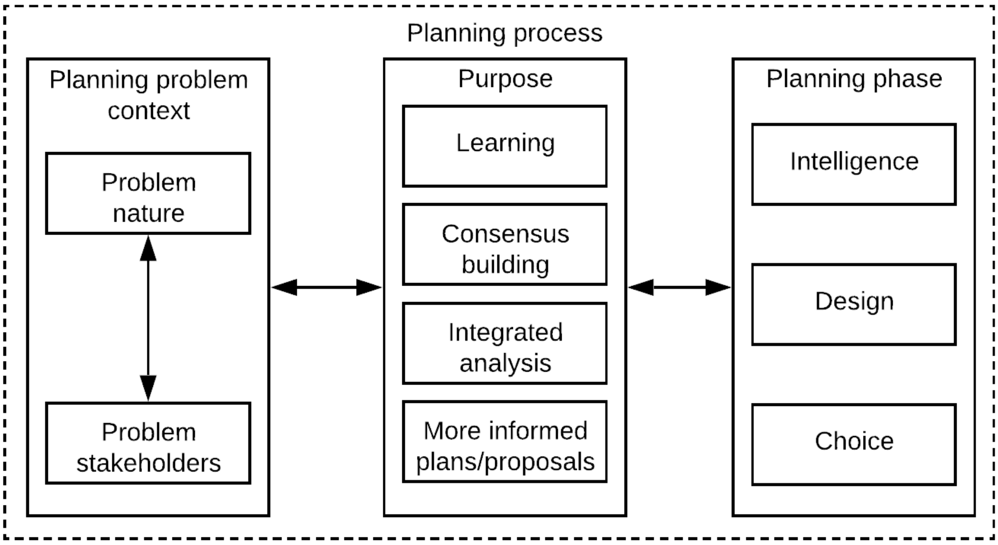

Figure 2-1. Maptable-based planning workshop context. Source: Authors; based on (Pelzer et al., 2014; Pelzer, Goodspeed, et al., 2015; Simon, 1960).

2.2.2. Space-Time Dimensionality for Group Work Collaboration

As mentioned in the introduction, a PSS workshop normally happens in a co-located and synchronous setting for group work collaboration. However, interaction among participants in collaborative planning processes may occur in different space and time settings. Four cases were identified (Isenberg et al., 2011; Maceachren & Brewer, 2004), namely: a) co-located synchronous: same place and same time, b) distributed synchronous: different place and same time, c) co-located and asynchronous: same place and different time and, d) distributed and asynchronous: different place and different time. Figure 2-2 illustrates those settings. Various methods for participation are applicable in each setting. For example, a group decision room (GDR), i.e., an electronic mediated meeting room enabling stakeholders dialogue (Pelzer et al., 2014) could be a suitable method for co-located and synchronous (same time) discussion. A web survey can be applied to distributed and asynchronous consultation, as has been implemented in SoftGIS (Kahila & Kyttä, 2009). As each setting will require different methods, specific support concerning enabling technologies is required (García-Chapeton, Ostermann, de By, & Kraak, 2018).

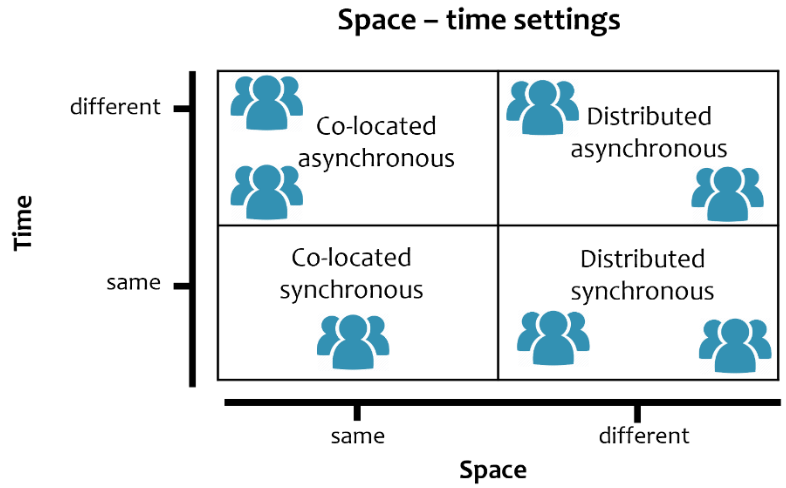

Figure 2-2. Space-time settings for group work collaboration. Based on (Isenberg et al., 2011).

A maptable is a PSS tool used so far in collaborative processes happening in a co-located and synchronous setting, e.g., a PSS workshop. In this study, inspired by our experiences in observing/conducting maptable workshops (Flacke, Boer, et al., 2020; Flacke & de Boer, 2017; Shrestha et al., 2017) where participation was limited by the size of maptable(s) applied, we also explore the possibilities to extend maptable capabilities to support a different space-time setting for group work collaboration and how relevant this kind of support for our intended user groups is.

2.3. Human-Centred Design and Agile User Stories

In the last decades, two main approaches have driven software development, namely human-centred design (HCD), and Agile software development ("Manifesto for Agile Software Development," 2001). The HCD approach is an iterative workflow of design and usability evaluation of interactive systems where the (human) user plays a central role. In such a way, the developed system becomes more usable. Agile software development comprises a set of practices to produce software in a short and usually well-defined period complying with user requirements. Agile methods apply incremental and iterative development cycles where the intended users provide feedback, and the goals of the system under development are adapted as user requirements are enlightened (Brhel et al., 2015). Although HCD and Agile techniques pursue slightly different goals, e.g., Agile techniques focus on working functionalities whereas HCD focuses on the usability, both methods work in close cooperation with the intended users and stakeholders of the system under design/development. The combination of HCD and Agile pursue delivering highly usable software (Brhel et al., 2015) in a short time.

For instance, a user story is a conventional Agile technique for collecting user requirements that encapsulates functional requirements in an informal language as perceived by the user (Brhel et al., 2015) and can be used within a HCD. It usually follows a template of who, what and why (Agile Alliance, 2019) as shown in Box 1, although other variants exist. The '[who]' is represented by Persona, i.e., an identified user or user role, the '[what]' describes the capability or software functionality that should be performed and the (optional) '[why]' that is located after the phrase so that, provides the rationality or benefits obtained by having that capability. A user story is an instrument for the dialogue between developers and users, and is often further discussed, for example, to add details and validation criteria, before its implementation. User stories can be gathered through different methods, such as user interviews, questionnaires, observation, and story-writing workshops (Dimitrijević, Jovanovic, & Devedžić, 2015).

Box 2-1. Standard templates for a user story

[Persona] *wants to* [perform a task] *so that* [achieve this goal]
As [user role], I *want to* [perform a task] *so that* [achieve this goal]

2.3. Methods

To conceptualize an interactive PSS tool for a maptable we conducted a comprehensive literature review on existing maptable applications to identify 1) potential user requirements of maptable users, and 2) shortcomings of current PSS software for horizontal, large touch devices. Furthermore, we conducted a series of semi-structured interviews with a carefully identified groups of maptable users to elicit their needs or expectations regarding the application under study. From these interviews, we derived user stories as concrete expressions of user needs. Moreover, we drew on insights gained from previous maptable-based PSS workshops (Flacke et al., 2019; Flacke & de Boer, 2017). Those user stories and experiences combined with the required baseline functionality of an online annotated map (Ramasubramanian & Albrecht, 2018; Wallin, Horelli, & Saad-Sulonen, 2010) formed the starting point for the conceptualization of the tool that is presented in this article. Figure 2-3 shows the workflow of our study that is elaborated in the following subsections.

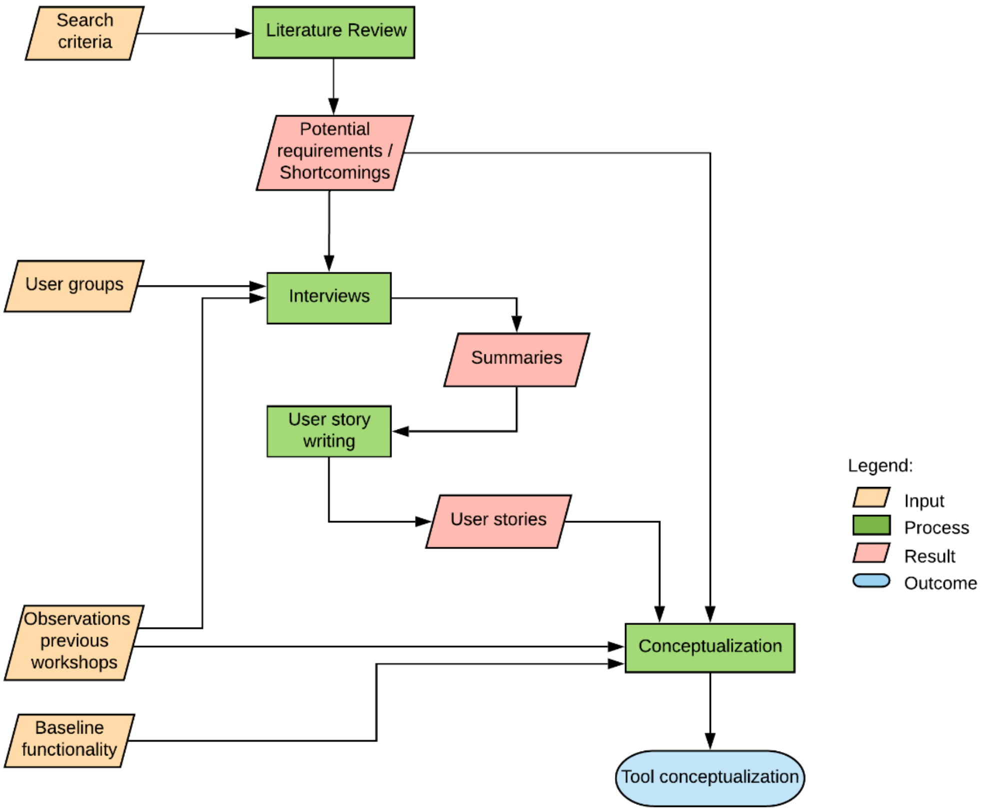

Figure 2-3. Methodology overview.

2.3.1. Literature Review

Three central sources of literature were reviewed for the period between 2008 and 2018, namely, Google Scholar, Scopus, and Web of Science. In Scopus and Web of Science, each search query was applied to the title, abstract, and article keywords. The criteria and search keywords used to build queries for each database format are given below:

- Keywords: urban planning, tools, maptable, multi-touch, collaboration. Synonyms for maptable: tabletop and touch device. Strings used were:
  a) planning AND tools AND maptable AND multi-touch AND collaboration;
  b) planning AND tools AND maptable AND collaboration.
- Language: English
- Type of publication: full text available in journals, proceedings.

Using the term "touch device" in google scholar returned more than 2000 hits. For that reason, that keyword was omitted in that search engine. The total number of papers returned by each source was: a) Google Scholar: 135, b) Scopus: 26, and c) Web of Science: 18. Through manual screening, we omitted non-relevant papers, i.e., papers not directly related to planning, or articles referring to tangible user interface (TUI) where the interaction is based on the combination of physical objects and computer vision technologies.
After manual screening the search resulted in 12 papers selected from a) Google Scholar: 10, b) Scopus: 2, and c) Web of Science: 0 (papers were already returned in the other sources). Another 17 papers were included in the review as they were relevant to the discussion on PSS software for a maptable. These papers did not appear in the initial result of the search; however, authors were aware of them, or they were found in the bibliography of the reviewed papers. Appendix A contains a list of the selected papers.

2.3.2. Semi-Structured Interviews with Intended Users as Part of Human-Centred Design and Agile User Stories

In this study, we employed a HCD to involve the intended users in the conception of the tool. Hence, we started the conception process of a digital interactive tool to support collaborative spatial planning by identifying intended user groups and their characteristics, selecting a sample from identified groups and interviewing them to generate user stories in a posterior phase. Four main groups of intended users were identified for semi-structured interviews, namely planning researchers, GIS experts, planning practitioners, and laypersons (Gueze & Jonker, 2013). All of the identified user groups had to be aware of a maptable and had used it at least once. Planning researchers are defined as professionals primarily dedicated to planning studies, whether having or not a background in GIS applications. Their research interest is mainly led by theoretical frameworks and planning problems instead of the supporting technology for addressing them. GIS experts are professionals or researchers highly skilled in the application of GIS technologies; they may have some knowledge of planning, but their central interest is the exploitation of GIS capabilities. This type of users can perform the role of chauffeur, develop models to be used in a maptable-based PSS workshop, or provide technical support during such a workshop. A planning practitioner is understood as a planning professional working in a private or public organization to develop plans or carry out projects related to land use interventions. This type of users may have or not expertise in GIS applications. A layperson or lay user refers to a person without specialized knowledge in planning or GIS. This kind of user can also be referred to as residents that have prior experience in planning sessions.

The objective of the interviews was to unpack user perspectives concerning the current validity and importance of the requirements found in the literature and identify new ones that may not have been reported on it. We interrogated the users' previous experience to understand the kind of application for which they have applied a maptable. Besides, we asked for the problem addressed, stakeholders involved in the process, the spatial analysis applied and the planning phase in which a maptable was used. We also enquired about the shortcomings of the PSS tool applied or aspects to be improved, and the expectations concerning a 'must-have' functionality of a new PSS tool under design. Furthermore, we asked for the need of support for different space-time settings and individual footprints, i.e., tracking individual contributions during a planning session with a maptable. The information collected through the interviews outlined above, was the input to extract user stories described in the following section.

In total, we interviewed 11 participants, 4 planning researchers, 3 GIS experts, 2 planning practitioners, and 2 laypersons. Those participants were selected given their experience with a maptable and their availability, e.g., time and location, for participating in the interviews. Interviews were (voice) recorded and summarized to provide the input for the systematic formulation of user stories. The interview process complied with the General Data Protection Regulation (GDPR) meaning participants were informed about the purpose of the interview, they gave consent to record it and to use it for the purpose of this research; collected data was not disclosed to third parties; and its processing and storage were performed following practices for data protection and privacy aligned with the GDPR.

Due to time availability and geographic location of our intended users, we derived Agile user stories from their interviews. Recordings and interview summaries were deeply scanned to extract expressions systematically. These impressions were translated into Agile user stories which are reported in the result section. Formulated user stories follow the template given in Box 1 by specifying a username or user role, the feature or functionality required and, optionally, the benefit that the user will attain by having that functionality in the tool. All user stories were checked by an external expert in software development and revised where applicable. In order to minimize the subjectivity endowed with this kind of data analysis method, interview audio, and summaries were revisited iteratively.

2.3.3. Tool Conceptualization

For the tool conceptualization we contrasted the requirements found during the literature review with those expressed as user stories. Besides, a baseline of functionalities provided in regular GI-based participatory tools such as annotated maps is taken as a basis of our tool. An annotated map enables users to explore spatial content encoded in geographic layers and add information via markers, comments, or media files. We also considered our own knowledge accumulated through the experiences obtained from attending or moderating planning workshops. The result of this conception process is presented through an illustration and a narrative describing the main components of our tool in Section 2.4.3.

2.4. Results

This section discloses the findings we obtained from the literature review and user interviews and presents the conceptualization of an interactive PSS tool for a maptable, narrowing down the many specific aspects to what is required in practice by users.

2.4.1. A Maptable: Potential Shortcomings and Requirements of Maptable Software Applications

Based on the literature, concerning: a) case studies where a maptable was applied; b) general shortcomings of the available PSS tools, i.e., software applications for this instrument; c) potential requirements; and d) our own experiences of maptable-based PSS workshops, we found the following.

Different studies in diverse sectors of applications emphasize the potential of a maptable to support collaborative spatial planning, for instance, to enhance the communication among different types of stakeholders, e.g., expert and non-expert, and offering analytical functionality to generate better-informed plans or proposals. The majority of the studies concerned strategic urban planning issues (Arciniegas, Janssen, & Rietveld, 2013; Dias et al., 2013), followed by planning studies related to climate (Janssen et al., 2014; van de Ven et al., 2016; van der Laan et al., 2013; Voskamp & Van de Ven, 2014) and environmental health (Shrestha et al., 2017). We also found applications in the energy sector (Flacke & de Boer, 2017), and transportation (Nagel et al., 2014). In several of those studies, scholars reported that the enhanced interaction provided by a maptable might lead towards knowledge sharing, knowledge combination, or consensus-building (Pelzer, Arciniegas, Geertman, & De Kroes, 2013; Shrestha, Flacke, Martinez, & Maarseveen, 2018).

Although a maptable has shown potential as demonstrated by the case studies, the authors also encountered some limitations. For example, it can accommodate only a limited number of people and can be intimidating for elderly or low digital literate stakeholders (Flacke & de Boer, 2017). Case studies also reported shortcomings of software applications, i.e., the digital tool implemented in a maptable, when delivering spatial content. This aspect is the focus of our research. The issues that were identified concerning software applications for a maptable are summarized as follows:

- Single root: GIS desktop applications do not fully exploit the touch capabilities because they have single-user roots, i.e., they were designed for a single user, i.e., one user at the time (Maceachren & Brewer, 2004; Vishkaie & Levy, 2012).
- Expert systems: conventional tools are developed for and by experts that can handle sophisticated technologies which may limit the participation of non-expert stakeholders (te Brömmelstroet & Schrijnen, 2010).
- Turn-taking: Turn-taking is a regular implementation of the collaborative group work, i.e., stakeholders use the software in turns, but the software itself is not aware of this and does not keep a record of those turns (Tse, Shen, Greenberg, & Forlines, 2006). Hence, individual contributions cannot be traced.
- Software offer: the offer of mature and stable GI-based software specially designed for supporting large touch devices and collaborative group work is scarce. Besides, the current offer does not satisfy the needs of most users (Russo et al., 2018b)
- Open-source software: open-source software tools that allow for collaborative development of extensible applications are scarce (Hewitt & Macleod, 2017).

In addition to the general software shortcomings mentioned above, we also listed the desired capabilities of a planning support tool as envisioned by researchers. We categorized those capabilities, also known as potential requirements as follows:

1. Navigation,
2. Data input,
3. Data management,
4. Spatial analysis,
5. Visualization and,
6. Other capabilities mainly dealing with extensibility and performance of the PSS tool.

Concerning navigation, scholars documented the need for mobile-oriented designed applications. This means apps with intuitive GUI (Graphical User Interface) adapted to an interactive surface, i.e., simple and minimal menus using larger buttons, and gesture-based user interaction (Viard, Bailly, Lecolinet, & Fritsch, 2011; Vonk & Ligtenberg, 2010; Zenghong, Yufen, & Jiaquan, 2012).

Capabilities for data input concerned advanced editing, namely: automatic closing of shapes, easy drawing of regular forms; copying, pasting, resizing, and rotate features; freehand drawing and annotation; adding markers or comments and typing via a virtual keyboard (Dias et al., 2013; Isenberg et al., 2012; Shrestha, Flacke, Martinez, & Maarseveen, 2018; Viard et al., 2011; Vishkaie & Levy, 2012; Vonk & Ligtenberg, 2010).

Potential requirements related to data management address information reuse and integration; for example, the integration of information via databases, map libraries and multiple sketching layers. Besides, import and export of parameters values, results or maps is desired (van de Ven et al., 2016; Vonk & Ligtenberg, 2010).

With regard to spatial analysis, scholars reported scenario planning, timely evaluation of alternatives via indicators, embedded GIS functionality and cost-benefit analysis as pivotal functions expected in a PSS tool (Dias et al., 2013; Eikelboom & Janssen, 2017; Flacke & de Boer, 2017; Janssen et al., 2014; Voskamp & Van de Ven, 2014).

In terms of visualization, scholars remarked the importance of a balance in the data used to limit the cognitive effort of stakeholders, e.g., by limiting the number of concurrent layers being displayed, showing a reduced number of indicators at once, and providing different visualization forms understandable for a wider audience, e.g., dashboards, linked visualizations of maps, charts, and graphs and efficient rendering of large datasets (Dias et al., 2013; Eikelboom & Janssen, 2017; Janssen et al., 2014; Nagel et al., 2014; Vonk & Ligtenberg, 2010). In addition, intuitive and interactive styling and advanced visualization such as 3D views were listed as needed for supporting planning processes (Dias et al., 2013; Flacke & de Boer, 2017).

Other relevant qualities for a PSS as understood by researchers refer to a) the performance of the tool, e.g., handling large datasets or cloud computing; b) the learning curve, i.e., guidance through workflows, well-structured help; and c) adaptable and understandable models (Champlin et al., 2019; Dias et al., 2013; Eikelboom & Janssen, 2017; Pelzer, Arciniegas, Geertman, & de Kroes, 2013; Viard et al., 2011).

In summary, based on the potential requirements and shortcomings found in the literature and our previous experience in attending and moderating planning workshops, we identified four dimensions to structure our interviews, namely:

a) Principal spatial analysis of a maptable PSS tool,
b) Must-have functionalities of a maptable PSS tool,
c) Tracking of individual contributions and,
d) Space-time settings for group work collaboration.

Dimensions a and b were chosen to stress the core of requirements that would enable users to achieve their intended tasks when applying the tool being conceptualized, i.e., the principal spatial analysis that is required and the minimum essential set of functions for a map-based PSS tool. Dimensions c and d were selected on the basis of our experience gathered during attending and moderating previous maptable-based PSS workshops, e.g., the limited window in space and time that people have to participate in a workshop and the lack of support in discriminating individual contributions. Besides, these dimensions imply functionalities that are not regularly included in a PSS tool, because they go beyond the standard or base level of performance of a GI-based tool.

2.4.2. User Stories Derived from the Interviews

In the following sections, we analyse the responses of the identified user groups structured by the identified requirements from Section 4.1, namely a) principal spatial analysis, b) must-have functionalities, c) tracking of individual contributions, and d) space-time settings for group work collaboration. For each dimension, exemplifying user stories are given, following the template presented in Box 1. For readability, we refer to our intended users in a general way, e.g., researchers instead of interviewed researchers. Also, when we refer to statements made by a specific respondent we identified her/him as follow: P_i represents a planning practitioner (i ranges from 1 to 2), R_j refers to a researcher (j ranges from 1 to 4), G_k refers to a GIS expert (k ranges from 1 to 3), and L_m states for a layperson (with m ranging from 1 to 2).

a) Principal Spatial Analysis

We found that the majority of case studies as reported by our respondents applied a maptable during an exploratory phase (intelligence), i.e., for gaining an understanding of the planning problem or issue at hand. In those cases, map visualization and essential input data functions, e.g., adding markers, were sufficient for the intended purpose. In other instances, impact evaluation via indicators was the principal spatial analysis used in planning workshops giving stakeholders immediate feedback on specific intervention proposals. Table 1 lists the responses of our interviewees, followed by examples of extracted user stories related to this topic.

Table 2-1. Principal spatial analysis

Group\Type of Analysis	Visualization/ Mapping	Impact Evaluation (Indicators)	SMCE	Simple Calculations
Practitioners	2	-	-	-
Researchers	4	1	1	-
GIS experts	2	1	1	1
Lay persons	-	2	-	-

Example of user stories:

As a planning practitioner, I want to integrate different layers *so that* I can quickly identify ideal locations for certain facilities.

As a researcher, I want to have a scenario analysis combined with impact analysis of alternatives *so that* I can see the effect of specific measures on the problem being tackled.

b) Must-have functionalities

In this dimension, interviewed users responded at different levels of details providing statements that were classified as non-functional and functional requirements. The non-functional requirements, also known as quality attributes, describe how the tools should be whereas the functional requirements refer to specific capabilities, e.g., calculations, input type, etc., desired for the new tool under construction. We listed below a summary of the must-have capabilities according to our interviewees, the first set of qualities are rather generic, whereas the following are specific:

Non-functional requirements:

- Customizable: a tool adjustable to the context and topic under discussion.
- Transparent: the user can know and modify any assumption of the tool.
- Interoperable: meaning easy integration with common GIS applications and formats, and portability of the resulting analysis.
- More intuitive interface: the UI of the new tool looks and works similarly to a tablet or mobile phone, e.g., simple interfaces with bigger buttons.

- Web-based: the app is available online.
- OS: the app is Open Source.
- Reliable: recovers from failures with minimum data loss.
- Complexity: the complexity of the tool according to the tackled phase of planning and the specific intended stakeholder participating in a workshop mediated by a maptable.
- Modularity: the application allows for a progressive addition of functions as the planning process advance.

Functional requirements:

- Data collection: adding markers to the map concerning the issue at stake.
- Sketching and adding notes: free-hand drawing and adding text notes on the map canvas.
- Impact assessment: provides immediate feedback on the effects on predefined indicators of sketched interventions being discussed.
- Scenario analysis: constructs and analyses future conditions concerning the problem at stake.
- (user-driven) Spatial Multi-criteria Evaluation (SMCE): stakeholders can perform a multi-criteria evaluation and tune its parameters.
- 3D views: visualization of tri-dimensional data.

Examples of user stories:

As a researcher, I want to have a GUI rich in pictures *so that* people with low education (e.g., unable to read) can easily use the application.

As a GIS expert, I want an application available on the web *so that* more people can participate remotely and integrate the result of that interaction into the discussion mediated by a maptable.

As a Researcher, I want an open-source application comparable to current private touch-oriented apps for a maptable so that users can have a satisfactory experience without the restrictions of private software.

As a layperson, I want to have an app that does not freeze so that participants remain engaged/active in the discussion.

As a Planning practitioner, I want to quickly draw in a few steps *so that* the process of proposing interventions can be faster.

As a Planning practitioner, I want to sketch on a maptable using free-hand gestures so that I can express ideas or concepts as I normally do during design discussions.

c) Tracking of Individual Contributions

Common applications for maptable-based PSS tools do not offer the capability for keeping track of individual contributions. We explored to what extent our intended users do need to discriminate individual inputs during a planning workshop where a maptable is used. Table 2-2 presents gathered responses in this matter, in which we observe that more than half of our participants judged tracking individual contributions of stakeholders as not important or slightly important.

Table 2-2. Tracking individual contributions

Group\Item	Very Important	Moderately Important	Slightly Important	Not Important
Practitioners	1	-	1	-
Researchers	1	-	1	2
GIS Experts	-	1	-	2
Lay Persons	-	1	-	1

Example of user stories:

As a researcher, I want to track individual inputs so that I can understand how stakeholders become more concrete across the planning session or whether changes in the proposal can be related to a communicational process (e.g., learning).

As a planning practitioner, I want to be able to discriminate individual interventions of participants so that I can understand who proposed a particular intervention during the planning workshop.

d) Space–Time Settings for Group Work Collaboration

In general, in the geospatial community, there is an increasing interest in supporting multi-user collaboration in different space-time settings, particularly in asynchronous distributed environments (Palomino et al., 2017). In this dimension, we enquired our users' perspective concerning how useful it would be having extended capabilities to accommodate interactions among stakeholders in distributed–asynchronous and distributed–synchronous settings (see Figure 2-2). This feature goes beyond the current support offered by a maptable in a co-located–synchronous setting that is typical of face-to-face planning workshops. Responses collected are listed in Table 2-3.

Table 2-3. Need for supporting different space-time settings

Setting	Group \Item	Very Important	Moderately Important	Slightly Important	Not Important
Distributed–Synchronous	Practitioners	-	-	2	-
	Researchers	-	-	3	1
	GIS experts	-	-	-	3
	Laypersons	-	-	1	1
Distributed–Asynchronous	Practitioners	-	-	-	2
	Researchers	-	1	2	1
	GIS experts	-	2	1	-
	Laypersons	-	1	-	1

In general, respondents considered the support for the distributed-synchronous setting not important or slightly important. However, some respondents envisioned potential uses cases that may require this kind of configuration, for example, in a professional environment where users remotely need to co-design proposals, and it is not possible to timely meet in face-to-face. Additional insights emerged concerning this issue. We listed those below:

- As participants or stakeholders, being located in different places, work on the same problem perhaps in different geographic contexts, a competitive rather than collaborative behaviour may be triggered (L_1). Hence, there is a potential risk of a group dominating the discussion (R_2, G_1). Besides, stakeholders need to feel comfortable with the applied technology, i.e., a maptable and the software application to effectively participate in a discussion (L_1).
- The group dynamic occurring in a particular space can be disturbed by the communication with another group. Hence, there is a risk of diverting the discussion from the planning problem at stake by focusing on the interaction with the other group (G_1).
- The logistic effort required to configure such a system to support distributed-synchronous setting would be quite complex and perhaps might not add significant value to the planning process. Besides, the benefits of applying a maptable rely on the face-to-face interaction among stakeholders that would be impeded by the increased complexity to synchronize inputs from remote and local groups (R_1).
- Communication among different groups working on a maptable, e.g., two parallel workshops could be useful for sharing results that each group

achieved separately, discussing them and perhaps building a consensual outcome (G_3).

Respondents reacted—to some extent—positively on the question of supporting distributed asynchronous settings in combination with a maptable-based workshop. Thus, although practitioners did not find this quality as relevant, more than a third of our interviewees recognized this aspect as moderately important. Use cases for this setting concerned data collection processes, e.g., collecting user preferences or knowledge relating to a specific planning issue via annotated maps, online survey, etc. Respondents provided their perspective on this issue as summarized below:

- Often, the workshop participants, i.e., stakeholders, want to know people preferences on the problem under discussion. However, those processes should not be synchronized (R_1, G_3). Instead, it is useful to have those preferences elicited prior to the workshop, e.g., via online surveys, geo-questionnaires or similar techniques and incorporate them as an input for the discussion (R_2, G_1).
- A potential use case of a distributed and asynchronous setting including a maptable is a variation of the think-pair-share approach (G_2) where users have their device, e.g., mobile phone or tablet for data collection or design proposals and their inputs are shared in a next group session. Then, the discussion on a maptable can take the input collected from individual participants or pairs into account (P_1, G_2).
- People contributing to a data collection process that served as input for a maptable session should be able to know about the overall result of the data collection process, e.g., aggregated responses, and the outcome that stakeholder achieved using that elicited data (G_1).

Example of user stories:

As a GIS expert, I want to have seamless integration between mobile data collection and the application in a maptable *so that* I can use the data collected in the field during a planning workshop without much effort.

As a researcher, I want to collect people's preferences beforehand *so that* those preferences can be used during a workshop session.

2.4.3. An Interactive Tool for A Maptable: A Conceptualization from User Stories

In the previous section, we elaborated collected responses with respect to the selected dimensions namely a) the principal spatial analysis, b) the must-have functionalities, c) tracking of individual contributions, and d) space-time settings for group work collaboration. Besides, we provided examples of user stories extracted from those responses. Here, building on the results for the selected dimensions and taking into account that there exists a difference between what can be technically supported and what users need (Geertman, 2002; Hewitt & Macleod, 2017), we present the main building blocks of the digital maptable tool (i.e., a software application) to support a PSS workshop in a planning process, illustrated in Figure 2-4. The envisioned tool has three central components offering support concerning mapping, analysis, and space-time settings (see Figure 2-2). The *mapping support* component contains three subcomponents, namely interactive map, data input and layer management. The interactive map provides a visual workspace where stakeholders can explore geographic information, i.e., geographic layers, through gesture navigation tools such as pinch, pan, rotate, etc. The data input element enables stakeholders to input data, i.e., attributes or characteristics related to a particular location represented in one or more layers that are handled by the layer management. Layers are usually offered by loading local files or consuming geoservices. Through the mapping support component, participants can explore geographic information such as plan interventions, create sketches, or submit data linked to a location via marker or pin. The interaction provided by the mapping support component is compared to an annotated map as it accommodates preferences collection, data input or local knowledge elicitation.
The analysis component (*analytical support*) concerns evidence-based methods to tackle the problem at hand. We distinguish two sets of analytical functions. The first set refers to standard features expected for most of our intended users. Compiled user stories indicate that users mainly need SMCE, scenario development, impact assessment via indicators and sketching. These analytical functions, including their output visualization, e.g., an indicator chart, can be applied to produce better-informed plans or decisions (van der Laan et al., 2013). The second set of analytical functions includes advanced functionality that is specific to the problem at stake and the purpose for which a maptable

will be applied. In this way, the application contains a set of common functions that most users require but allows for extension through the advanced and problem-based functions to be developed in close collaboration with stakeholders of the application, i.e., following an HCD approach. The *space-time support* component provides functions to accommodate participation in two different space-time settings: co-located synchronous and distributed asynchronous since compiled user stories confirmed some application cases for these settings (see the previous section). For co-located and synchronous settings, the conceptualized tool enables participation via gesture support, i.e., pinch, pan, minimal use of regular mouse and keyboard and a mobile-oriented GUI design, e.g., bigger buttons and simple interface. For distributed and asynchronous settings, the tool provides easy integration with GI-based open-source tools for mobile data collection. The three building blocks of the tool aim to support the social interaction (synchronous and asynchronous) among stakeholders and the analysis required to support collaborative spatial planning.

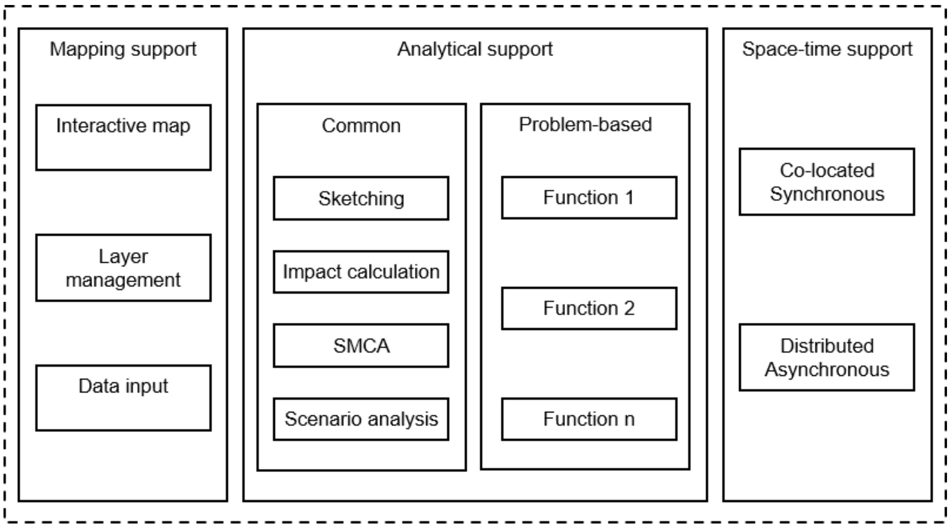

Figure 2-4. Central components of an interactive PSS tool for a maptable.

2.5. Discussion and Conclusions

The central aim of this chapter was to conceptualize an interactive PSS tool to be used in a maptable that carefully considers requirements expressed by intended users of such a tool.

By involving the intended users in the conception of the tool, we revealed a discrepancy between the understanding of scholars and developers with respect to what users need and what they do. Thus, concerning the principal spatial analysis dimension, most cases reported by our respondents did not perform spatial analysis because the process was at an early stage, or the intended outcome was knowledge elicitation or social learning. In other cases, the central spatial analysis applied was the calculations of predefined indicators to assess the impact of proposed interventions. This indicates that often scholars/developers seem to be more ambitious than our respondents when addressing spatial planning processes. Hence, what our intended user group is requiring is tailored but straightforward instruments, rather than complicated or time-consuming models. This issue was also discussed in earlier studies (Geertman, 2017).

As regards must-have functionalities of the PSS tool to be developed, our respondents provided insights at different levels of abstraction, showing a preference towards contextualized tools. In other words, a tool adjustable to the planning problem being addressed and the characteristics of the stakeholders to enable equity in participation. With respect to this, some of the extracted requirement were comparable with those found in the literature, whereas others were not mentioned, e.g., cloud computing or movement data analysis (Dias et al., 2013; Palomino et al., 2017). This led us to argue that, in general, in the context of collaborative spatial planning processes mediated by a maptable, users want simple, transparent, fast-to-setup, interoperable, and affordable tools that aid in their planning tasks.

Concerning the support of group work collaboration via recording individual contribution, our users found this feature irrelevant, especially when the problem at stake addresses personal opinions rather than institutional perspectives. This result challenges findings of previous studies (Tse et al., 2006), but needs to be further researched as we conducted interviews with only a small number of potential users. In terms of extended capabilities of a maptable for supporting distributed settings, e.g., as part of a collaborative GIS (Sun & Li, 2016), users reacted moderately positive towards distributed–asynchronous setting and the use of the output of such a process as input for planning workshops mediated by a maptable. In contrast, our respondents were sceptic concerning distributed-synchronous settings, arguing that such setup imposes complexity and demands technical facilities, e.g., a broadband and stable internet connection that is not always available. This finding is quite interesting because the need for supporting group work in different space-time settings has been broadly discussed (Andrienko et al., 2007; Isenberg et al., 2011) but, so far, few software solutions implemented capabilities for those settings (García-Chapeton et al., 2018). Also, in the field of spatial planning, detailed studies on this issue require further investigation as our number of interviewees is modest.

For several years, scholars discussed the mismatch between what planning practice needs and what has been developed. In this research, we involved representative intended users of our PSS tool to be developed in the conceptualization process through a combination of methods, namely interviews and Agile user stories. By extracting user stories from the interviews, we have conceptualized a tool that effectively addresses the requirements of those intended users. However, elicited requirements were rather generic, and new ones might arise or evolve in the implementation phase which can be handled in iterative collaboration with users in an HCD approach. Our research has laid down the foundation for future maptable tool development to support collaborative planning processes. A next step in our research is to actually implement our conceptualized tool in a co-creation process fed by inputs collected in frequent iterations with a problem-specific focus group. Feedback will not only concern functionality, but also usability aspects of the tool.

3. OGITO, an Open Geospatial Interactive TOol to support collaborative spatial planning with a maptable [*]

[*] This chapter is based on: Aguilar, R., Calisto, L., Flacke, J., Akbar, A., & Pfeffer, K. (2021). OGITO, an Open Geospatial Interactive Tool to support collaborative spatial planning with a maptable. Computers, Environment and Urban Systems, 86, 101591. https://doi.org/10.1016/j.compenvurbsys.2020.101591

Abstract

Maptables are increasingly used to support collaborative spatial planning processes. Despite the proven benefits and claimed potential of using a maptable in such processes, software applications specifically designed for this device are still scarce. Moreover, often-used applications do not fully exploit the touch functionality of a maptable, or have low usability. To address this gap, we developed and evaluated the Open Geospatial Interactive TOol (OGITO), an open-source software application designed to support collaborative spatial planning processes with a maptable. To develop such tool, we combined human-centred design and Agile software development principles in a co-design effort with intended users and stakeholders. Through iterative development cycles and feedback from users, OGITO was evolved until it satisfied user expectations. In a case study on community mapping in Sumatra, Indonesia, a sample of users evaluated OGITO's usability. Case study participants reported high satisfaction with this tool for the tasks and context given. Our research shows the added value of iterative development and user feedback for improving and further development of the tool's usability and functionality.

3.1. Introduction

Maptables are increasingly used to support stakeholder participation in planning support system (PSS) workshops (Flacke, Shrestha, & Aguilar, 2020; Pelzer, Arciniegas, Geertman, & De Kroes, 2013). In these workshops, a maptable, i.e., a large horizontal surface that shows geo-spatial content and enables user groups to interact with the displayed content via touch gestures, is the central digital instrument for supporting collaborative spatial planning tasks (Aguilar, Calisto, Flacke, Akbar, & Pfeffer, 2021). However, with a few exceptions such as Phoenix (Geodan, 2018), planning support software applications designed specifically for maptables are still scarce. Furthermore, frequently used applications are poorly adapted to maptables (Eikelboom & Janssen, 2013) and have usability shortcomings: their single-user, desktop-oriented interfaces, with e.g., small icons and list-based menus, are designed for vertical screens and interaction with a mouse and keyboard. Hence, they do not function well in a touch-enabled device such as a maptable, where the display is usually bigger, and the interaction relies on touch gestures (Viard et al., 2011; Zenghong et al., 2012). Consequently, their usability remains low, limiting the support that they can provide to decision-making processes. Besides, the range of open-source software for maptables is rather limited (Hewitt & Macleod, 2017). The usability of PSS tools, such as maptables, has often been mentioned as a limiting factor of their adoption in planning practice (Russo et al., 2018a; te Brömmelstroet & Schrijnen, 2010), as has been reported in various studies (Champlin et al., 2019; Pelzer, 2017; te Brömmelstroet, 2013). However, the diversity of the PSS evaluation criteria, and specifically of usability criteria, makes comparison between PSS tools difficult (Pan & Deal, 2020; te Brömmelstroet, 2013). Also, evaluation criteria often exclude usability aspects as an outcome of the user-system interaction in terms of effectiveness, efficiency and satisfaction (Russo et al., 2018b).

A frequent recommendation to improve the usability of interactive systems, and, in particular, of planning support systems (PSS), is to involve intended users in developing them, e.g., by following a human-centred design (HCD) approach (Giacomin, 2014; Russo et al., 2018b). HCD is an interactive design workflow in which user expectations and user feedback are continuously considered throughout the design process. HCD can be combined with Agile software development principles - these are practices for quickly delivering software that satisfies customer needs. The combination of HCD and Agile strives to incrementally produce timely, usable systems (Brhel et al., 2015). However, despite the growing interest in such a combination of methods in computer science research fields (Ardito, Baldassarre, Caivano, & Lanzilotti, 2017b; Jurca et al., 2014), there remains a need for studies reporting on the benefits of applying HCD or its combination with Agile for developing PSS software for maptables (Flacke, Shrestha, et al., 2020). Therefore, the purpose of this study is to develop a software application, namely OGITO — an Open Geospatial Interactive TOol — and to test its usability in a maptable-based workshop setting. To do so, we applied a combination of HCD methods and Agile software development principles. OGITO's initial conceptualization had already been generated with intended users (Aguilar, Flacke, & Pfeffer, 2020), and served as an initial input to the further development process. A case study in community mapping in Sumatra, Indonesia – the participatory budgeting process Musrenbang (Akbar, Flacke, Martinez, Aguilar, et al., 2020) — provided the context for a formal usability evaluation of OGITO.

OGITO provides a map-based visualization platform to facilitate communication and interaction of stakeholders and supports knowledge elicitation, that is especially relevant at the early phase of a planning process. Elicited knowledge is used in planning for investigating and understanding the problem at hand; in our case study, it was the preparation of the village map necessary for the Musrenbang process (Akbar, Flacke, Martinez, Aguilar, et al., 2020). The following section introduces the background concepts (PSS usability evaluation, HCD, Agile development). Section 3.3 elaborates on the methods, and Section 3.4 presents the results. Section 3.5 discusses those results and enumerates lessons learned. Finally, Section 3.6 provides a conclusion, outlining directions for future work.

3.2. Background

3.2.1. Usability evaluation in PSS

The usability of PSS tools is important because usability may influence the perception of users regarding the added value for planning of such tools and their potential to support participation of marginalized groups (Ballatore, McClintock, Goldberg, & Kuhn, 2020; Russo et al., 2018b; te Brömmelstroet, 2017a). However, there is a lack of uniformity with respect to usability evaluation of PSS tools. For example, Trubka, Glackin, Lade, and Pettit, (2016) evaluated usability by considering solely the level of expert knowledge or training required to use the PSS tool. Pelzer (2017), in contrast, adopted ten variables in his evaluation including data quality, transparency and calculation time, among others. Russo et al., (2018a); and Russo et al. (2018b) construed usability as a system quality comprising learnability, efficiency, memorability, low error rate and user satisfaction. In contrast, Champlin et al. (2018) broadened the concept of usability across the context of actual use by including items related to the tools applied, and items related to the setup and facilitation of the PSS workshop where such tools were used. Examining Participatory GIS (PGIS), a form of PSS used for planning, Ballatore et al. (2020) decomposed usability into five dimensions: user interface, spatial interface, learnability, effectiveness, and communication. Meanwhile, specific studies reporting on usability evaluation of PSS tools from the human-system interaction perspective are still scarce Russo et al., (2018a) or, in the case of maptables, non-existent. For these reasons, this study adopts the usability framework of the International Standard Organization (ISO, https://www.iso.org/). In the ISO framework, usability is defined as the extent to which users can achieve their tasks with effectiveness, efficiency and satisfaction in a specified context of use (European Committee for Standardization, 2018). Usability is treated as an outcome of system use, and the context includes the intended users, their tasks, goals, and the characteristics or conditions where the system is applied.

3.2.2. HCD

Human-centred design (HCD; European Committee for Standardization, 2019), in practice also referred to as user-centred design, is an iterative design approach where the intended user plays a pivotal role. User feedback guides iterative refinement of typical activities such as a) specification of the context of use, b) specification of user requirement, c) production of design solution, and d) validation of such designs. HCD is widely seen as optional or as adding extra effort and cost. In consequence, HCD is rarely considered (Bednarik & Krohns, 2015; Richter & Flückiger, 2014). However, a few studies in the literature confirmed that incorporating the user in the development of a system produces systems that users consider highly acceptable (Trubka et al., 2016; Vonk & Ligtenberg, 2010). Nevertheless, those studies did not explicitly use an HCD approach during the development of the software application, even though they reported close cooperation with intended users.

3.2.3. Agile methods

Agile methods for software development are highly collaborative, iterative and focused on delivering working software in short periods, ensuring that customer needs are satisfied (Jurca et al., 2014). Agile or "rapid" development techniques such as Scrum, eXtreme Programming (XP), and Dynamic System Development (DSD), share a number of principles such as a) development of incremental functionality, b) focus on the development of working code instead of documentation, e.g. exhaustive requirements specification, c) face-to-face communication among stakeholders and developers, d) short cycles or iterations in which feedback is collected and goals are adapted, and e) flexibility to allow the redefinition or reprioritization of requirements (Anand & Dinakaran, 2016). Agile methods have become widely adopted in the software industry but their focus on functionality and added value for the customer do not, strictly speaking, pursue usable software (Brhel et al., 2015).

3.2.4. Combining HCD and Agile methods

Recently, there has been an increasing interest in combining HCD and Agile development software methods in computer science research (Anand & Dinakaran, 2016). Both methods have commonalities, but also pursue rather different objectives. Specifically, both approaches involve intended users, and apply iterations, continuous testing and prototyping (Ardito et al., 2017b). However, the aim of HCD is to produce highly usable interactive systems whereas Agile methods aim to meet customer requirements in a short time. Thus, combining both methods aims to deliver highly usable software in short time (Brhel et al., 2015), and can be done in different ways (Da Silva, Martin, Maurer, & Silveira, 2011). For example, development could involve a longer initial step to define the interaction design before starting the development phase, or could use working prototypes for usability inspection or evaluation, or could include usability elements in user stories (Ardito et al., 2017; Da Silva et al., 2011). Our study builds on earlier work where users were involved in PSS software development such as reported by Trubka et al. (2016), who combined Agile methods for software development and user involvement in implementing the Envision Scenario Planner, a tool for precinct geodesign.

3.3. Methods

We integrated Agile and HCD methods in the design and development workflow of OGITO (see Figure 3-1). This integration implied an upfront application platform selection and the consideration of previously generated user stories that this research builds on (Aguilar et al., 2020). The following subsections describe the development and evaluation of OGITO.

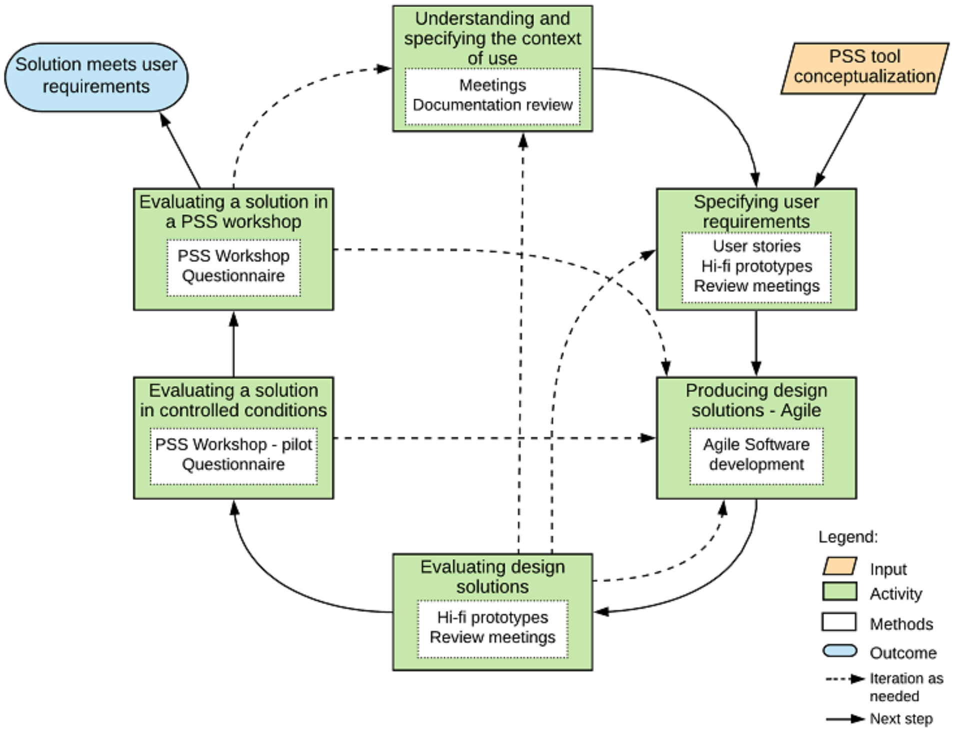

Figure 3-1.Workflow and methods to develop and evaluate a PSS tool based on HCD and Agile.

3.3.1. Selection of the application platform

The selection of OGITO's application platform, i.e., the software components through which OGITO operates, was based on reported and verified user needs (Aguilar et al., 2020; Hewitt & Macleod, 2017; Levine & Prietula, 2014; Steiniger

& Hunter, 2013). The four main needs were: a) support for gestures (e.g., pinch, pan, rotate), b) simple and mobile-oriented GUI, c) open-source, and d) integration with other tools in the geospatial ecosystem (Palomino et al., 2017). Support for gestures was selected as primary factor as a maptable is a touch-operated device, and interaction becomes more natural when participants use gestures (Viard et al., 2011). A simple and mobile oriented GUI entails minimal use of menus and dialogs, instead preferring icons and gestures for user–system interaction. This kind of GUI is desirable due to the increasing use of (map-based) mobile applications. Open-source access was chosen for its open collaboration opportunities, supplemented by a free usage license (Levine & Prietula, 2014). Integration within the geospatial software ecosystem is important because users require interoperability between different geospatial applications, for example, by using common formats (Palomino et al., 2017) and Open Geospatial Consortium (OGC) standards.

3.3.2. Iterative development and evaluation of OGITO

The workflow depicted in Figure 3-1 illustrates the iterative development and evaluation of OGITO. This workflow distinguishes six principal activities: understanding and specifying the context of use, specifying user requirements, producing design solutions, evaluating design solutions, evaluating solution in controlled conditions, evaluating a solution in a PSS workshop. Various methods were applied (i.e., focus groups, high-fidelity prototyping, user stories, Agile software development and review meetings).

To *understand and specify the context of use*, we collected and analysed information from two sources: available written documentation, and information from application stakeholders. The documentation analysis entailed reviewing available documents listing the goals of the intended users and describing the characteristics of the Musrenbang process. The Musrenbang is a participatory budgeting process in which villagers discuss and decide the allocation of a portion of municipal or public funds (Akbar, Flacke, Martinez, & van Maarseveen, 2020; Grillos, 2017). To gather stakeholder information, a series of face-to-face meetings were conducted with the application stakeholders who described the PSS workshop purpose, the planning process in which it was embedded, the environment where the application would be used, and the tasks that intended users were expected to complete during the workshop. Information collected from both of these sources was combined into a narrative detailing the context of use that fed into subsequent steps of the development workflow.

For *specifying user requirements*, a focus group was formed with representative application stakeholders and users (Paetsch, Eberlein, & Maurer, 2003). This focus group comprised three planning researchers, one GIS researcher and one technical GIS expert. All participants had experience with maptables. The objective of this focus group was to provide comments and suggestions during the review meetings. Working software prototypes of OGITO, also called high-fidelity prototypes, were presented to the focus group. Using high-fidelity prototypes in review meetings is very common in HCD and Agile practices (Ardito et al., 2017; Da Silva et al., 2011), as they enable users to test the software functionality in addition to evaluating the user interface or inter action design. Feedback from the focus group was translated into user stories describing a) user needs (Brhel et al., 2015; Dimitrijević et al., 2015), b) improvement proposals, and c) bugs or errors. User stories generated during the OGITO conceptualization phase (Aguilar et al., 2020) and related to community mapping were also included.

The *production of design solutions* followed Agile principles for software development. This entails close collaboration between two parties: representative stakeholders and users (i.e., the focus group) and the application developers (i.e., the researchers). In short development cycles (iterations), a subset of the software functionality was implemented as a high-fidelity prototype that the focus group tested. Several iterations of programming and feedback were performed until the prototype attained acceptance among the focus group participants. An initial step was required to produce a hi-fidelity prototype which required setting up development and application platforms. Then, iterations of programming and user feedback were conducted approximately every 2 weeks.

To create the working prototypes, a software development framework was chosen as it allows for rapid creation of applications by providing reusable code for generic tasks, and predefined architectures for applications and resource-testing. To select the framework, a number of factors were considered, specifically a) support for gesture, b) integration with map visualization libraries, c) open-source code, d) developer community size, and e) long-term support.

To *evaluate the design solutions*, participants of the focus group were given a list of tasks to perform with the application (OGITO prototype). The tasks concerned testing the functionality implemented based on feedback from prior review meetings. These meetings, conducted periodically, approximately every 2 weeks, can be comparable to the Sprint review meeting of the Scrum method for evaluating the software produced in a development iteration (Paetsch et al., 2003; Anand & Dinakaran, 2016; Wadhwa & Sharma, 2015). In addition, we explored user perceptions of the working prototype, e.g., the number of clicks required to achieve a specific task. Feedback collected concerned errors or bugs in the application, or enhancement proposals related to usability aspects or to functionality itself. Errors or bugs were prioritized and addressed accordingly, whereas enhancement proposals were negotiated between the developer and application stakeholders considering the effort required for their implementation. Additionally, requirements were elicited or expanded upon through the group discussion during these review meetings (see above paragraph). Hence, feedback provided by the focus group helped to improve not only the functionality but also the visual appearance and operation mode of OGITO. In this way, the working prototype evolved until it reached acceptance among the focus group participants. Afterwards, the usability of the tool was comprehensively evaluated. A formal evaluation of the usability of the design solution, in this case a fully functional prototype of OGITO, was conducted in a) controlled conditions, i.e., pilot PSS workshops and b) in an actual PSS workshop with the users of the case study. In both cases, the framework described in Section 3.3.3 was used, with the context and goals of the PSS workshops participants utilizing OGITO, and the usability measures applied to evaluate the outcome of the use. The evaluation involved field validation, for which users reported their perceptions about OGITO (Aguilar et al., 2020; Ballatore et al., 2020; Tullis & Albert, 2013) by filling an anonymous questionnaire after finishing a community mapping workshop using OGITO (see Appendix B). The questionnaire aimed to assess usability as the extent to which these users could map the village in a participatory setting with effectiveness, efficiency and satisfaction in a given context of use (see usability framework in Section 3.3.3).

3.3.2.1. Evaluation in controlled conditions

Evaluating OGITO in controlled conditions began with two pilots of the designed planning workshop, with participants who shared similar characteristics with our intended users (Benyon, 2010). Two groups of approximately ten people participated in these pilots. The first group included Master degree students and PhD degree candidates. The second group was formed mainly of laypersons and a few professionals. In these pilots, the elements of the PSS workshop, tasks and questionnaire were tested so they could be adjusted if required. The workshop elements consisted of structure, order of tasks, instructions to be given by the moderator and the mapping workflow. The tasks and questionnaire were tested to determine whether the tasks were doable and the questions understandable. Both workshop pilots were conducted in the local language (Bahasa) to be used during the PSS workshop with the participants in the case study.

3.3.2.2. Evaluation in a PSS workshop with real users

After considering the feedback collected in the pilot meetings, the OGITO's usability was evaluated in two PSS workshops held in Denai Lama and Kramat Gajah, both located in Sumatra, Indonesia. In both cases, the participants, who were village residents, were asked to produce a) a village map of the current situation including facilities, roads, borders and land use including conflicting areas if applicable (for example discrepant village borders or land use), and b) a proposed development map indicating community-suggested interventions. Such maps are required by current regulations in the country and can be used in the participatory budgeting process later on.

3.3.3. Usability framework

We contextualized the definition of usability of an interactive system (European Committee for Standardization, 2018) to our study. Hence, we defined the usability of OGITO as the extent to which a user group can produce a participatory map of their village in maptable-based PSS with effectiveness, efficiency and satisfaction. Figure 3-2 illustrates the framework used to conduct the usability evaluation in a maptable-based planning workshop with end users. In the workshops, users were asked to complete community mapping tasks using OGITO in a maptable. Specifically, they were to produce two maps: a village map and a proposal development map. The first included existing facilities, roads, water bodies, land use and borders, including any conflict areas. The second map indicated interventions to be submitted for approval and funding in the Musrenbang. A very high resolution (VHR) satellite image (50 cm), acquired for the project, was inserted as a background layer, enabling participants to identify and draw map elements in each village. Each image, a natural colour composition (pan-sharpened), covers the full study area, i.e., the village and its boundaries, and was captured between January and May, 2019 by the WorldView2 platform (https:// worldview.earthdata.nasa.gov/).

The usability dimensions, namely effectiveness, efficiency and satisfaction (European Committee for Standardization, 2018; Russo et al., 2018b), were evaluated using the indicators described below:

- Effectiveness: assessed by perceived completeness, meaning that the map is complete (sufficiently represents the current situation), and perceived participation, meaning that everyone is able to contribute in the discussion that produced the maps. To accomplish that, OGITO should enable participants to locate themselves spatially, i.e., to locate their village on a map, and to draw all the necessary elements of the community maps to be produced.
- Efficiency: measured by human effort, expressed as perceived ease of use and learning time.
- Satisfaction: evaluated by self-reported user attitudes toward the product.

The above-listed dimensions and their indicators were selected while considering the nature of participatory processes in map table-based workshops that impose additional challenges to evaluating the usability of PSS tools (Ballatore et al., 2020). For example, a traditional usability evaluation based on the duration of executing tasks would not sufficiently reflect the usability of a PSS tool used in a maptable-based planning workshop (Pelzer, Goodspeed, et al., 2015) because other factors such as discussions among participants might take place between map-drawing events, which would affect the duration measures. Besides, qualitative self-reported indicators, e.g., perception of ease of use, considered as subjective have proven to be as valid as quantitative observations (Tullis & Albert, 2013).

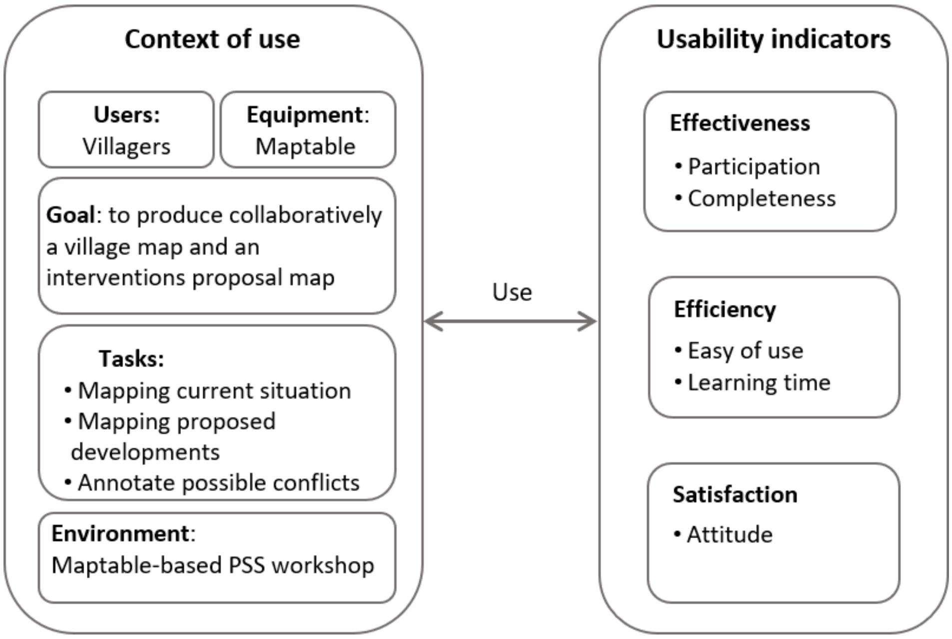

Figure 3-2. Usability framework. Adapted from Guidance on usability (ISO9241-11:2018 - NEN-EN-ISO 9241-11) and Ballatore et al. (2020).

3.4. Results

This section presents the architecture and central components of OGITO and reports the usability evaluation.

3.4.1. OGITO application platform

We explored current stable, mature, open-source desktop GIS software platforms to assess their suitability for OGITO, considering the criteria described in Section 3.2.1., namely a) intuitive gesture support, b) simple and mobile-oriented GUI, c) source openness, and d) integration with the geospatial ecosystem. Current open-source GIS desktop software, e.g., QGIS (www.qgis.org) or Ilwis (https://52north.org/softw are/software-projects/ilwis/), did not adapt well to touch screen interfaces. Specifically, these applications have a limited gesture support, and their GUI (menus, dialogs) is designed for desktop screens. Although it was possible to customize some of their GUIs, the complex interfaces included many functionalities not required for our intended users to achieve their tasks. Keeping in mind the spatial limitations of

accommodating people around a maptable, we selected a web platform given the flexibility that such implementation may offer regarding space and time for group collaboration. This means that the application could be used remotely, enabling a broader audience to participate. This characteristic has become especially relevant after restrictions were put in place to limit the spread of COVID-19. In many countries, face-to-face meetings were replaced by online communication.
Angular (https://angular.io) was chosen as the application development framework because it allows the reuse of open libraries for common tasks, integration of gesture support via hammer js (https://hammerjs.github.io/), and inclusion of open libraries for specific tasks. For example, OpenLayers (https://openlayers.org) for map visualization, and angular material (https://material.angular.io/) for GUI elements. Besides, Angular is open-source, and enables applications to be created using components suitable for short production times. It also benefits from the long-term support offered by Google and a large community of developers. As result, OGITO is built on widely accepted components (Figure 3-3) already available in the current geospatial software ecosystem (Palomino et al., 2017).

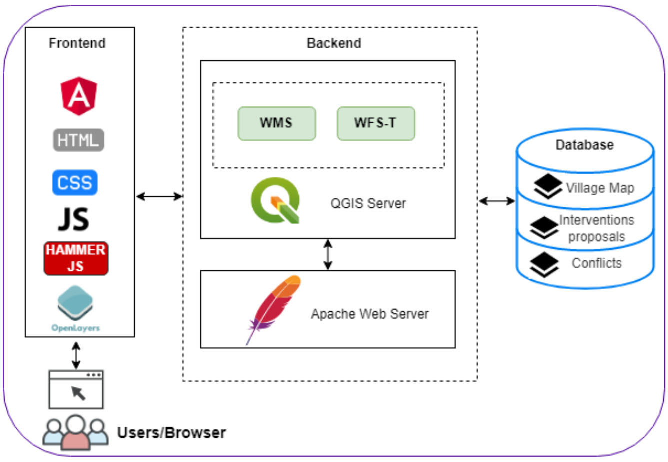

Figure 3-3. Components of OGITO.

Figure 3-3 shows the frontend and backend architectures of OGITO. The frontend uses Angular together with basic web technologies such as HTML, CSS and Javascript, and includes specific libraries, i.e., OpenLayers (https://openlayers.org/) and HammerJS for map visualization and touch-gesture support respectively. The backend components consist of QGIS Server (https:// qgis.org/) as a provider for geowebservices (OGC WMS and WFS-T) configured on top of Apache Web Server (https://httpd.apache.org/). Such geowebservices provide access to the database that could be, e.g., a set of structured shapefiles, geopackages, or a more complex structure implemented in a Spatial DBMS (Database Management System). OGITO thus uses well-tested software components and widely recommended geospatial formats and standards (Falco & Kleinhans, 2018).

3.4.2. Components of OGITO – layout

OGITO is implemented in several modules that provide an interactive map, layer management, data input and sketching. Figure 3-4 shows the OGITO interface layout where the interactive map canvas is the central component. This map (1) responds to common gestures such as pinch (for zooming in), unpinch (for zooming out), pan (one or two fingers), and rotate (two fingers). In addition, a zoom control bar and buttons for zooming in and zoom out are provided at the left side of the map. A graphical scale bar is also provided, at the low left corner. The layer management (2) allows layers to be shown, hidden, and reordered. Data input and sketching tools are supplied on the main toolbar (3), an editing toolbar (4), and a symbol panel (5). All of these functions are available via touch, so no mouse or keyboard is required. OGITO's minimalistic and simple design provides only the tools needed for the purpose at hand.

OGITO accommodates data input of a) simple geometry types (points, lines and polygons) and, b) composite geometries i.e., simple geometry types combined in the same layer. A tap gesture is used to draw points whereas lines and polygons can be digitized using free-hand drawing (one finger). The digitizing of polygons can be done through free-hand drawing of a closed polygons (https://openlayers.org) or a line. Such a line will be automatically closed within a certain configurable distance threshold to form a valid polygon. Points, lines and polygons can be deleted or moved.

By selecting a certain symbol from the symbol panel (see Figure 3-4 – box 5), the element being drawn takes the category associated with that symbol. In this manner, intuitive data input is offered without using a mouse or keyboard. Map symbology, i.e., geometry styles, followed the technical specifications for the production of village maps in Indonesia (Akbar, Flacke, Martinez, Aguilar et al., 2020).

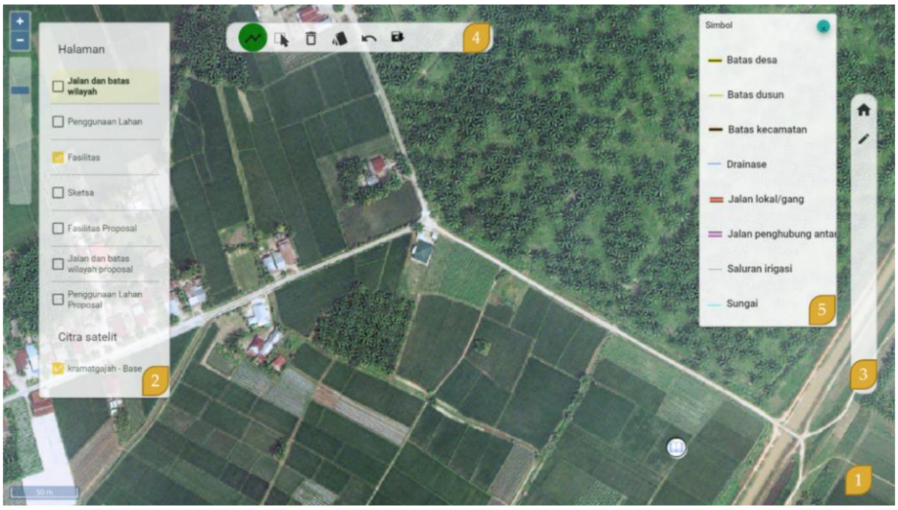

Figure 3-4. OGITO Layout (Screenshot from application, with boxed numbers added for explanations in this chapter).

Focus group feedback, collected during the periodical meetings, helped to improve OGITO design and functionalities. Below we provide some examples of such feedback and the response provided by the developing part:

- The functionality provided to draw closed polygons using free-hand drawing did not fully satisfy user expectations because the polygon being drawn partially covered the area of digitization (https://openlayers.org/en/latest/examples/draw-freehand.html). Therefore, it was proposed to include free-hand lines that could be automatically closed within a configurable distance threshold. This enhancement was developed and tested, by users, in a subsequent meeting. Users considered this feature as relevant giving the flexibility that it brings when drawing in a surface such as a maptable.
- A preliminary design used red colour to indicate the current tool in use; however, a user mentioned “I associate red colour with stop as in the traffic light”. As response, the design used green colour instead (see Figure 3-4).
- Users observed that sometimes, the map was flickering while points were drawn via tap gestures. This was solved in a subsequent development cycle and tested in the following focus group meeting.

Figures 3-5a and b illustrate the current situation as mapped by the participants from Denai Lama village and the proposals map. Three main developments were proposed namely 1) a drainage system for the village to prevent damage to the road infrastructure and sanitization issues due to water accumulation; b) a paved road to link communities from neighbourhoods I and III as current access is only a dirt road, and 3) a bridge to connect the main road of the village with the main road of its neighbor - the Denai Sarang village.

a)

b)

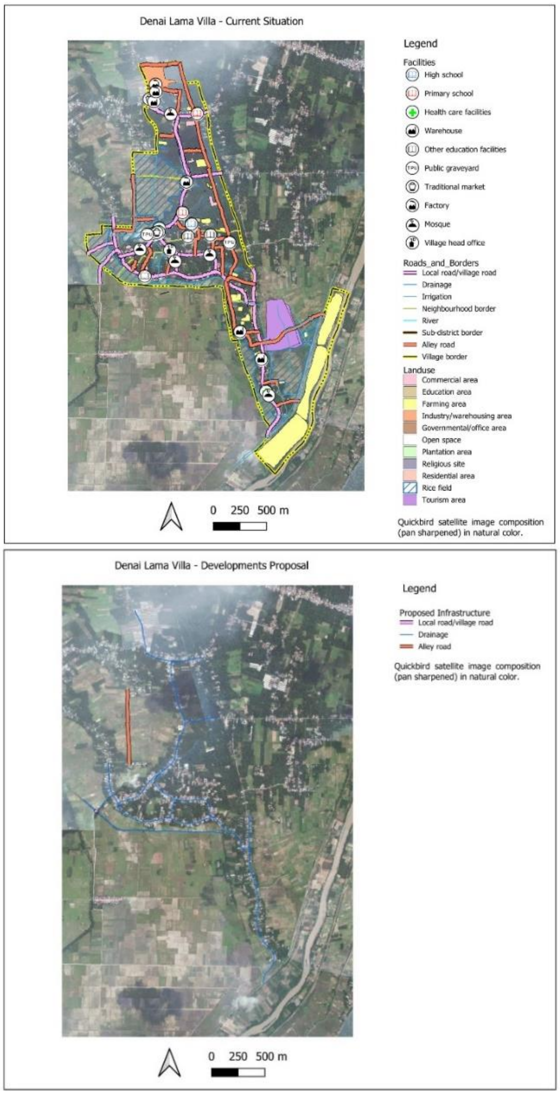

Figure 3-5. Maps produced during the workshop in Denai Lama Village:
a) Current situation and b) Proposed developments (interventions).

3.4.3. Usability evaluation

We evaluated OGITO's usability through post-workshop questionnaires (see Section 3). During the workshops, a moderator (professional planner) facilitated the discussion and guided the activities, the main researcher and developer of OGITO was available to provide technical support as needed, and workshop participants used the tool themselves (see Figure 3-6a -b).

a) Kramat Gajah b) Denai Lama

Figure 3-6. Workshop participants. Source: first author.

Pilots of the workshop, i.e., evaluation in controlled conditions, provided useful inputs concerning the sequence of activities of the workshop and the mapping workflow. During the pilots, all participants were able to conduct the selected tasks (see Figure 3-2). Nonetheless, during the first pilot, it was observed that drawing elements (points, lines and polygons) would be better understood gradually, for example, first drawing point elements, followed by lines and polygons. The sequence of these tasks was therefore adjusted accordingly. Also, first pilot participants suggested explaining a step-by-step mapping workflow for digitizing consisting of a) select type of element to draw, b) select symbol, and c) draw the desired element in the map (see boxes 4 and 5 in Figure 3-4). In such a manner, lay persons that are not familiar with GIS can adhere to a defined sequence of steps to facilitate digitizing with OGITO.
All participants from the controlled conditions workshops reported that they understood the questionnaire well (see Appendix B), hence no adjustments were needed for that.

Below, we provide an overview of workshop participants' characteristics and analyse their questionnaire responses concerning OGITO's usability. The number of participants attending the workshops is too small to derive significant statistical patterns; we only compute percentages to describe patterns in their responses.

3.4.3.1. Workshop participants

The workshops were attended by 16 participants in Denai Lama, and 10 participants in Kramat Gajah. All participants were males. More than two thirds of the participants in both villages were aged between 31 and 50 years, while the portion of participants aged 51–65 was 18.7% in Denai Lama and 40.0% in Kramat Gajah (see Table 3-1).

Table 3-1. Age group of participants per village (N=16 and N=10 respectively).

Age group	Village	
(years)	Denai Lama (%)	Kramat Gajah (%)
18–30	6.3	0.0
31–50	75.0	60.0
51–65	18.7	40.0

Regarding the level of education (Table 3-2), in both villages, a small portion of the participants only finished primary school whereas 80% or more had completed a high-school level of education at junior or senior level. Very few participants were university graduates.

Table 3-2. Highest level of education of participants per village (N=16 and N=10 respectively).

Level of Education	Village	
	Denai Lama (%)	Kramat Gajah (%)
Primary school	6.3	10.0
Junior High School	25.0	30.0
Senior high school	56.3	50.0
Diploma	6.2	0.0
Bachelor	6.2	0.0
Not say	0.0	10.0

Concerning computer and digital maps use (Table 3-3), in both villages, half of the participants had never used a computer, but contrastingly, more than a quarter of participants reported using a computer every day. Also, low familiarity with digital maps was observed among participants in both villages. Almost half of the Kramat Gajah participants had never used a digital map, whereas in Denai Lama, although we see greater diversity in use frequencies, more than half of the participants had never used a digital map.

Table 3-3. Frequency of use of computer and digital maps per village (N=16 and N=10 respectively).

Frequency of Use	Village			
	Denai Lama		Kramat Gajah	
	Computer (%)	Digital Map (%)	Computer (%)	Digital Map (%)
Daily	37.5	12.5	30.0	0.0
Every week	6.3	12.5	0.0	0.0
Once per month	0	6.3	0.0	0.0
Few times per year	6.2	12.5	20.0	60.0
Never	50.0	56.2	50.0	40.0

We also asked about our participants' previous experience in community mapping activities (Table 3-4). In general, participants were aware of community mapping workshops. In both villages, 60% or more of the participants reported experience in at least one community mapping workshop. In comparison, the fractions of participants who had never participated in any participatory mapping activities in Kramat Gajah and Denai Lama were 30.0% and 18.7%, respectively.

Table 3-4. Experience of workshop participants in collaborative mapping activities (N=16 and N=10 respectively).

Participation in a group mapping activity (times)	Village	
	Denai Lama (%)	Kramat Gajah (%)
Never	18.7	30.0
1–2 times	68.7	60.0
3–5 times	6.3	10.0
More than 5 times	6.3	0.0

3.4.3.2. Usability ratings

Concerning effectiveness, users responded "highly positive" about the functionality of OGITO (see Figure 3-7) for a) identifying their village on the map and b) drawing all the elements identified by participants (see questionnaire in Appendix B). In Denai Lama, more than 90% could locate or identify their village in the map while In Kramat Gajah, all participants could perform this task. Concerning the capability of drawing all the elements in a map as identified by participants, the response was highly positive as well. In Denai Lama, most respondents agreed or strongly agreed while 6.3% gave a neutral response. In Kramat Gajah, a 100.0% agreed or strongly agreed to this question.

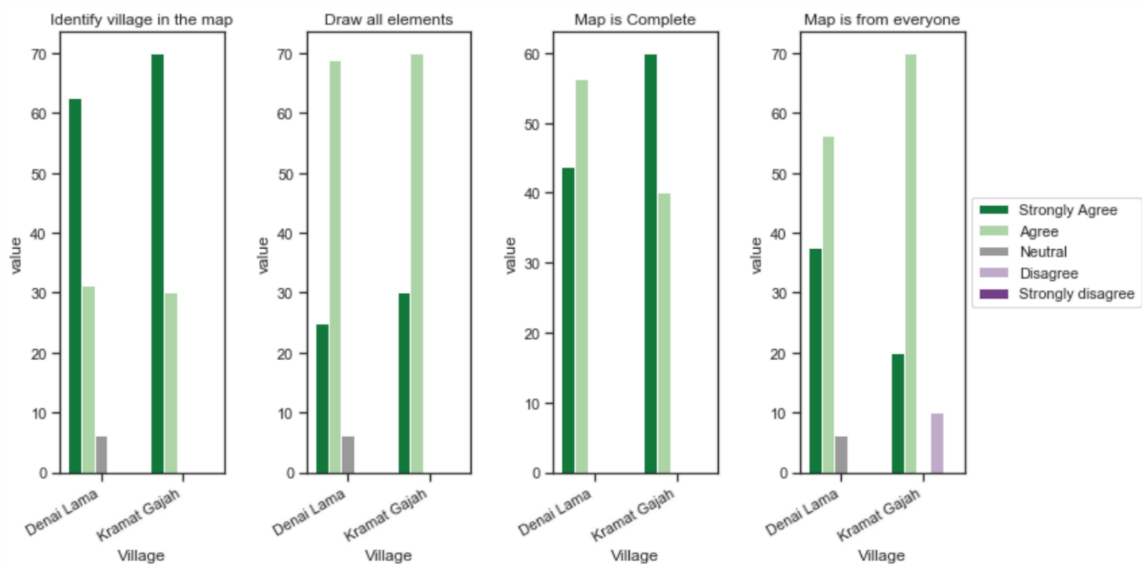

Figure 3-7. Responses of participants concerning indicators of effectiveness of OGITO.

Participants also gave positive responses concerning the completeness of the map (i.e., reflecting the current situation of their village), and their participation (i.e., everyone could contribute). All respondents from Denai Lama agreed or strongly agreed that the produced map reflected the situation; respondents from Kramat Gajah provided similar positive responses. Concerning participation, more than 90% respondents from Denai Lama agreed or strongly agreed that the produced map was the result of everyone's contributions; 6.3%

responded neutral. In Kramat Gajah participants also agreed or strongly agreed on the same statement whereas 10.0% disagreed on this statement.

Efficiency was measured by human effort, expressed as perceived ease of use and learning time. This means the effort that users have to make to achieve tasks such as map navigation and editing, i.e., drawing and deleting elements in a map; and how long it took participants to learn how to perform such tasks.

Participants reacted positively about effort and learning time (Table 3-5) to achieve tasks such as map navigation and editing (drawing and deleting elements in a map). In Denai Lama, participants rated OGITO very positively for ease of use; 87.5% rated the tool as easy or very easy to use, while 12.5% found OGITO neither easy nor difficult, to use. Rating for specific tasks, e.g., navigate, draw, and delete, were equal or higher.

In Kramat Gajah, participants responded moderately positively about ease of use. 50% rated OGITO as easy or very easy whereas 30% found OGITO difficult; the remaining 20% found OGITO neither easy nor difficult to use. Regarding the individual tasks, participants rated equal or higher. However, 20% found the tool difficult to navigate and to draw whereas 10% found it difficult to delete elements.

Table 3-5. Ease of use of OGITO per task, grouped by Village (N=16 and N=10 respectively).

Ease of use \Tasks	***Village***							
	Denai Lama				***Kramat Gajah***			
	Navigate	**Draw**	**Delete**	**Overall**	**Navigate**	**Draw**	**Delete**	**Overall**
Very difficult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Difficult	0.0	0.0	0.0	0.0	20.0	20.0	10.0	30.0
Neutral	6.3	0.0	6.3	12.5	10.0	10.0	10.0	20.0
Easy	68.7	81.3	75	68.8	50.0	60.0	40.0	40.0
Very easy	25.0	18.7	18.7	18.7	20.0	10.0	40.0	10.0

Regarding the learning time (Table 3 6), the majority of respondents, in both villages, perceived neither a short nor long learning time. In comparison, 18.7% of the participants in Denai Lama and 10% in Kramat Gajah responded that they needed a long time to learn how to use OGITO. In both villages less than a quarter of participants responded that they needed a short time. Only 6.3% of participants from Denai Lama found that a very short time was required to learn how to use OGITO.

Table 3-6. Learning time as reported by participants in both villages (N=16 and N=10 respectively).

	Village	
Learning time	Denai Lama (%)	Kramat Gajah (%)
Too long	0.0	0.0
Long	18.7	10.0
Neutral	56.3	80.0
Short	18.7	10.0
Very short	6.3	0.0

Concerning satisfaction, respondents from both villages showed a positive attitude toward the use of OGITO during the mapping. Table 3-7 lists their responses in this regard. The majority of participants were satisfied or very satisfied; and participants from Denai Lama reported higher levels of satisfaction than participants from Kramat Gajah.

Table 3-7. Satisfaction of participants concerning OGITO (N=16 and N=10 respectively).

	Village	
Satisfaction	Denai Lama (%)	Kramat Gajah (%)
Very satisfied	43.8	30.0
Satisfied	56.2	70.0
Unsure	0.0	0.0
Dissatisfied	0.0	0.0
Very dissatisfied	0.0	0.0

3.5. Discussion

This study applied a combination of HCD and Agile methods to develop a maptable software application for planning support named OGITO, tested with users in PSS workshops. Overall, participants reacted positively towards the tool. On all three usability dimensions, users gave the tool generally positive scores. We surmise that this result was obtained by involving users in the iterative development process of the tool, as it was also found in similar studies (Vonk & Ligtenberg, 2010), and that our findings provide evidence of the benefits of the user involvement during PSS tool development (Russo et al., 2018b). In Kramat Gajah, a few users found it difficult to use OGITO. This response can be explained by the low digital map literacy reported in this community (see Table 3-3) as such users might experience difficulties when managing web maps (Gottwald, Laatikainen, & Kyttä, 2016). In consequence, to overcome these difficulties we could extend the time for the tool exploration prior to the tasks execution and provide incremental guidance (Barnard, Bradley, Hodgson, & Lloyd, 2013).

By combining HCD and Agile methods, we addressed both functionality and usability via close cooperation among stakeholders of the application, users and development parties in frequent review meetings. These frequent review meetings and feedback collected from the focus group shaped OGITO into a lightweight application with a simple interface that provides the required functionality that satisfied both the application stakeholders and the users. Testing the application periodically was useful, allowing timely detection of pitfalls and discussion of improvements.

While previous studies such as te Brömmelstroet (2017), Trubka et al. (2016) or Pelzer (2017) measured usability as the ease of use or user-friendliness of PSS tools, our study explicitly provided insights into the effectiveness, efficiency and satisfaction from the user–system interaction perspective. These insights corroborate the importance of the usability in PSS evaluation studies that recently focused on the usefulness of PSS tools (Flacke, Shrestha, et al., 2020; Pelzer, 2017). Nevertheless, the understanding of both usefulness and usability remains important, as particularly does their interplay (te Brömmelstroet, 2017a).

This study is limited in offering insights related to an often-mentioned challenge of the integration of HCD and Agile that concerns the combination of the workflows of two different teams: design, and development (Ardito et al., 2014). The first author, with expert support, both designed and developed the tool, and designed and conducted the usability evaluation. For this reason, there was no friction or challenge to address or report. This is not, however, the case for most software development projects.

Our workshops were only attended by males. This concern has been previously reported (Beard, 2005). We cannot draw conclusions about the reasons for the low participation of females. In future studies, separate workshops for females can be organized to provide a more open environment for their participation and hence achieve a more inclusive evaluation. We also observed that some participants disagreed with the statement that the map produced was the result of everyone's ideas. This might be explained by the self-organization of the groups that delegated most of the drawing to one of the participants who was a village officer. However, a deeper analysis and different kind of data documenting the participation and conversation dynamics are required, which is beyond the scope of this research.

3.6. Conclusions and future work

This study aimed to develop a software application, namely OGITO — an Open Geospatial Interactive Tool, and to test its usability in a maptable-based workshop setting. The tool developed was well-received by workshop participants who had never used a maptable before. They could use OGITO without assistance during a community mapping workshop, found it easy to use, and reported high overall satisfaction. Despite of the discussed limitations of our study, this result confirmed that including the intended users in the development of the tool, i.e. of OGITO, led to a usable tool that just provides the required functionality (an Agile principle). Besides, our study contributes to the broader literature by reporting a usability framework for the development of PSS applications considering human–computer interactions. This framework, following established criteria from the ISO and the European Committee for Standardization, addresses the inconsistency of usability criteria when comparing different PSS. Future work involves a) the evaluation of memorability, i.e., the sufficiency of recalling the handling of OGITO when participants attend multiple workshops, b) improvement to the current version of OGITO considering the feedback collected during the usability evaluation, c) the current version does not accommodate calculation functions and queries since they were not demanded by the users, the development of the next version of OGITO will include analytical functionalities, and d) exploration of bias in participation due to usability.

4. Stakeholders engagement in noise action planning mediated by OGITO – an Open Geospatial Interactive TOol. *

* This chapter is based on: Aguilar, R., Flacke, J., Simon, D., & Pfeffer, K. Stakeholders engagement in noise action planning mediated by OGITO – an Open Geospatial Interactive TOol. Submitted for publication.

Abstract

Noise action planning (NAP) requires collaboration between stakeholders, given the harmful health effects of noise and the subjectivity of how individuals perceive noise. Maptables can be utilized to mediate in such a collaborative spatial planning process. However, open software applications specifically designed for those devices are still limited or mismatched with user needs. This study presents the co-design and development process of OGITO-noise, an Open Geospatial Interactive Tool intended for maptables users. We explore in the study to what extent such tool can be usable and useful in supporting collaborative NAP in practice. Our methods combine Agile software development and Human-centred design (HCD) in a hybrid fashion, namely remote co-design meetings and face-to-face testing, to develop an open application that was found by our intended users usable and useful. Those methods were utilized during a pandemic but can also be used when dealing with geographic or resource limitations.

4.1. Introduction

Noise Action Plans are planning instruments "designed to manage noise issues and effects, including noise reduction if necessary" (EU, 2002, p. 4). They are defined in the Environmental Noise Directive 2002/49/EC (END; EU, 2002) adopted by the European Union (EU) in response to the increasing noise pollution and its harmful effects, e.g., annoyance and sleep disturbance linked to an increased rate of cardiovascular diseases and a lower performance of children at school (Lee, Garg, & Lim, 2020). Noise action planning (NAP) objectives are to diminish the harmful health effects of noise and preserve environmental noise quality where it is positive, e.g., quiet areas (King, Murphy, & Rice, 2011). NAP requires the involvement of different stakeholders such as municipal authorities, environmental organizations, and local community members (Hintzche & Heinrichs, 2018; Maisonneuve, Stevens, Niessen, & Steels, 2009; Riedel et al., 2017). Nonetheless, the participation of various professional stakeholders in noise action planning is scarcely reported in the literature.

A relatively recent tool used to engage with stakeholders in collaborative spatial planning processes is the so-called maptable. This large horizontal touch screen enables users to interact with geospatial content and offers a platform that accommodates enhanced communication and collaboration (Flacke, Shrestha, et al., 2020; Pelzer, Arciniegas, Geertman, & De Kroes, 2013). Maptables capabilities are particularly advantageous when complex concepts are discussed. For example, Shrestha, Flacke, Martinez, & Maarseveen (2018) utilized a maptable to explore Cumulative Burden Assessment (CuBA), a complex concept that included noise nuisance. In this study, participants were able to interact with each other, learn about CuBA and co-produce knowledge. Likewise, Arciniegas & Janssen (2012) used maps and drawing tools implemented in a maptable as an effective mechanism to support communication among stakeholders with different background while developing a land use plan for a polder. Maptables have also been used as a planning support (PS) tool in other contexts, including water management, renewable energy, climate change adaptation, urban redevelopment, and walkability (Janssen et al., 2014; Pelzer, Arciniegas, Geertman, & de Kroes, 2013;

Voskamp & Van de Ven, 2014). However, there remains a paucity of evidence reported on using a maptable to support collaborative NAP.

Previous research has established the poor usability of PS tools and the disparity between PS tool capabilities and user needs as important determinants of the low uptake of PS tools in practice (Russo et al., 2018a; Vonk & Ligtenberg, 2010). To tackle this problem, the adoption of Human-Centred Design (HCD; European Committee for Standardization, 2019) has been recommended, being an iterative design workflow where users are involved through the design, development, and evaluation of an interactive system. Nonetheless, with a few exceptions (Aguilar et al., 2021; Rittenbruch et al., 2021; Trubka et al., 2016), studies that systematically investigated this strategy are still scarce (Flacke, Shrestha, et al., 2020). In addition, the development of (open) software designed explicitly for maptables has received scant attention (Hewitt & Macleod, 2017). In order to address these two shortcomings and to test our hypothesis that maptables can be effectively utilized in supporting collaborative NAP where different stakeholders are involved, the main aims of this study are 1) to co-design and develop an Open Geospatial Interactive Tool, namely OGITO-*noise*, and 2) to explore to what extent it can be usable and useful in supporting collaborative NAP. Our methods include Agile user stories, human-centred iterative software development, and evaluation of usability and usefulness of OGITO-noise for a case study in a real-world scenario.

This chapter is structured as follows: Section 4.2 provides a brief discussion of stakeholder involvement in noise action planning and co-design and evaluation of PS tools; Section 4.3 elaborates on the methods, Section 4.4 presents the results. Section 4.5 discusses these results and lists lessons learned about co-designing an interactive planning support tool in pandemic times. We draw conclusions in Section 4.6 and outline directions for future work.

4.2. Background

4.2.1. Stakeholders' involvement in noise action planning (NAP)

NAP demands collaboration between different professional stakeholders, given the harmful health effects of noise and the subjectivity of how individuals perceive noise. Also, noise abatement measures might impact other city areas, for example, infrastructure or road safety (Hintzche & Heinrichs, 2018). The

END also requires municipalities to involve the public in NAP (EU, 2002, p.7). Citizen involvement, particularly at the early stages of such a process, can be beneficial as people are the 'local experts' who experience the noise daily (Van Renterghem, Dekoninck, & Botteldooren, 2020; Xiao, Lavia, & Kang, 2018). Nonetheless, most reported citizen involvement in END-related activities mainly focused on data collection using the citizen as a sensor (Alsina-Pagès, Hernandez-Jayo, Alías, & Angulo, 2017; Murphy, Faulkner, & Douglas, 2020). Also, understanding modelled maps of noise indicators that are the central instrument in NAP can be challenging for non-experts (Mietlicki et al., 2020; Riedel et al., 2017). For this reason, several research initiatives have been conducted to facilitate the participation of non-experts in such a process (Mietlicki et al., 2020; Van Renterghem et al., 2020). However, these initiatives did not exploit spatial visualization capabilities, e.g., data structuring and management in geoinformation layers or interactive mapping. Also, utilizing maptables to facilitate stakeholders' participation in NAP or promote communication and understanding of noise concerns has not yet been investigated.

In this study, we identified stakeholders in NAP as our intended users for an interactive application on maptables in two groups: a) researchers that conduct participatory activities utilizing maptables, i.e., planning workshops in which they play the role of moderator, chauffeur, or promotor (Pelzer, Goodspeed, et al., 2015), and b) professionals and laypersons, who interact with a maptable and participate in the discussion because they are stakeholders of the problem at hand. In the following, we call the first group *user-partners* and the second *end-users*.

4.2.2. Co-design of planning support tools

Co-design is generally understood as a participatory activity where participants and professional designers work together in the design development process (Rittenbruch et al., 2021; Sanders & Stappers, 2008). Nonetheless, there are multiple definitions and uses of terms (Heijne et al., 2018). In this research, we understand co-design as an approach for geospatial interactive system design where users not trained in design collaborate actively with professionals, e.g., system designers and developers. Such collaboration implies providing information about the context of use and feedback while testing early design solutions (Bont, de et al., 2013).

Previous research suggests that user participation in the design and development of a PS tool has two central objectives: a) improving the PS tool usability and, therefore, its acceptance, and b) unravelling requirements through a dialog between the development party and users. For example, Vonk & Ligtenberg (2010) reported close collaboration with intended users to develop a sketch tool in a so-called socio-technical approach. The resulting tool, aimed at professionals, was better accepted than the original prototype that was developed following a traditional design process, i.e., complete cycles of the cascade method for software development. In another study, Trubka et al. (2016) used Agile and co-design methods to develop a web-based tool for precinct geodesign, visualization and assessment. The co-design approach encompassed software development iterations (prototype), user feedback collection about the prototype and its refining based on such feedback. Users evaluated the final prototype as positive and with a high level of usability. Recently, Rittenbruch et al. (2021) conducted a series of co-design workshops with their industry partners to shape RAISE, an interactive scenario exploration tool to support land value uplift under different development scenarios (Pettit et al., 2020). The co-design process accommodated the development of a tool that addressed the needs of its intended users. Aguilar et al. (2021) also described a combination of Agile and HCD methods to develop an open interactive tool that supports budgetary processes. Their study showed that frequent iterations of development and user feedback led to high self-reported user satisfaction. This study draws on their approach.

4.2.3. Evaluation of planning support tools

Usability evaluation of PS tools is conducted in various ways in previously published studies (Aguilar et al., 2021; te Brömmelstroet, 2013). In this study, we understand usability, an essential component of HCD, from the Human-Computer System Interaction (HCI) perspective that is the "extent to which a system can be used to achieve certain tasks with effectiveness, efficiency and satisfaction in a specified context of use" (European Committee for Standardization, 2018, p.6). This perspective is adopted because the body of norms related provide a common set of concepts and basic guidance that facilitates the reproducibility of the usability evaluation. The usability evaluation is contextualized to the tasks that users are expected to achieve during NAP workshops.

A system can be usable without being useful. Therefore, it remains important to consider both dimensions in evaluating PS tools (Silva, Bertolini, te Brömmelstroet, Milakis, & Papa, 2017). The usefulness or added value of a PS tools has been debated in the literature (Champlin et al., 2019; Pelzer, 2017). So far, however, this has not been closely examined in the context of NAP. This research focuses on collaborative NAP and considers PS tools as mediators for social interaction while addressing spatial planning problems (Foth et al., 2009; te Brömmelstroet & Schrijnen, 2010), in our case, NAP. Therefore, the term usefulness is used here to refer to what extent a PS tool can be used during a planning workshop supported by a maptable to a) collect stakeholders' perceptions concerning noise-related issues and b) facilitate communication and interaction among participants to define measures tackling those noise-related issues, or reach consensus about them.

4.3. Methods

The co-design, development, and evaluation of OGITO-*noise* build on previous work related to PS tools development in close collaboration with stakeholders and intended users to achieve highly usable PS tools that satisfy the user needs (Aguilar, Flacke, & Pfeffer, 2020; Aguilar et al., 2021). To do so, our methods combined Agile user stories (Brhel et al., 2015), iterative software development and evaluation of usability and usefulness applied to a case study. The following subsections elaborate on this approach.

4.3.1. Agile user stories

We utilized Agile user stories (Brhel et al., 2015) to understand the context of use and elicit user requirements of OGITO-noise. Figure 4-1 depicts the process from user stories generation to low-fidelity prototypes design and their refinement.

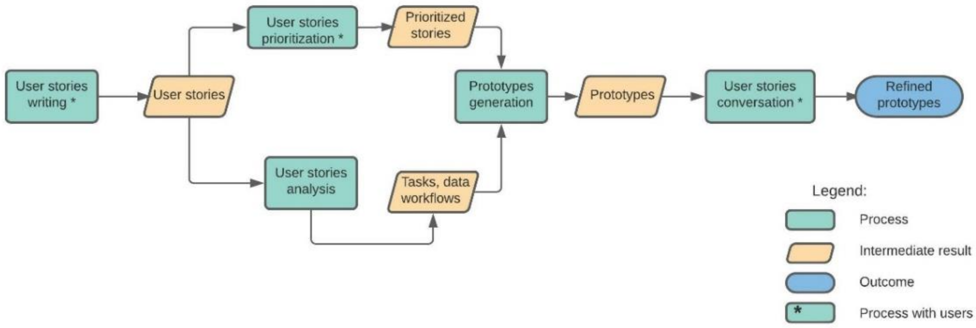

Figure 4-1. Process from user stories to low-fidelity prototypes design and its refinement.

User stories were generated with our *user-partners* during a *user-stories writing* workshop. Five participants, one environmental health researcher, three planning researchers and, one GIS technician attended the activity. Collected stories followed the template displayed in Box 4-1, specifying *Who*, *What*, and *Why* of a particular capability or feature of a system – in this case OGITO-*noise*. The *Who* indicates the user role or user group; the *What* denotes the software capability, whereas the *Why* is optional and refers to the benefit of having such capability.

Box 4-1. Common templates for a user story

[Persona] wants to [perform a task] so that [achieve this goal]
As [user role], I want to [perform a task] so that [achieve this goal]

Given the restrictions intended to prevent the spread of the Covid-19 disease, the user-stories writing workshop was conducted remotely. In an online meeting of two hours, workshop participants were introduced to the user story concept and format, and several examples were given. Next, participants were asked to "generate" user stories. We used a 'role play' format, meaning that participants were instructed to express the needs of their corresponding user group as well as another user group, e.g., expressing a user story for a role of an Environmental planner that was not represented among group participants. To maximize the speed of user stories generation, one person was in charge of writing the story while participants formulated them out in turns. The session was video recorded, with the consent of all participants.

The *user stories prioritization* was conducted asynchronously via an online questionnaire. Participants prioritized the previously collected stories following the MoSCoW scheme that classifies user stories as *Must be*, *Should be*, *Could be,* and *Won't be* (Racheva, Daneva, & Buglione, 2008). Stories prioritized as *Must be* are considered critical and need to be implemented, *Should be* stories can be implemented later whereas *Could be* and *Won't be* stories are beneficial but not required to be implemented.

The objective of the *user stories analysis* was to identify the user tasks during collaborative NAP and the required geospatial data. We drew on our experience from facilitating and attending maptable-based participatory workshops (Flacke & de Boer, 2017; Flacke, Shrestha, et al., 2020) to identify the user tasks. Then we conceptualized a workflow based on these tasks for a participatory NAP workshop using a maptable. Such a workshop aimed to gather local perception concerning noisy and quiet areas and preference for noise abatement measures. To determine the geospatial dataset to be included in the tool, we analysed each prioritized user story to identify any input data required for its implementation and the output data that it would produce. For the first, we selected open or publicly available data whereas for the second we designed geographic information layers stored in a geospatial database. We also included background layers for map orientation. Written stories and video recording of the user-story-writing workshop were revisited iteratively to minimize the inherent subjectivity in our analysis.

In the *prototype generation*, only prioritized stories, *Must be* and *Should be* stories, were further analysed to produce initial design solutions illustrated in low-fidelity prototypes. Those low-fidelity prototypes were discussed in a *user-stories conversation* workshop. The objective of this activity was a) to reach consensus among participants about the meaning of stories that remained unclear for some participants as expressed in the online survey and their priority, b) to validate the proposed workflow for prioritized stories. As stories were discussed, participants expressed their agreement or disagreement with the workflow presented. Notes were taken and the session was video recorded after getting consent from participants. Workflows were adjusted accordingly and implemented in the development phase.

4.3.2. Iterative development

Design solutions were progressively developed following an Agile approach, meaning four-week sprints (development iterations). These sprints allowed for the incremental development and early testing of the application while engaging in a collaborative dialog with our *user partners* that provided feedback, discussed changes on requirements or confirmed previously adjusted workflows. These sprints allowed for incremental development and early application testing while engaging in a collaborative dialog with our *user-partners*, who provided feedback, discussed changes on requirements or confirmed previously adjusted workflows. A sprint 0 was used to a) set up the application platform, b) organize the required dataset, i.e., creating and populating the database, and c) restructuring OGITO's code (Aguilar et al., 2021). Next, we implemented prioritized user stories in subsequent sprints. After each sprint, design solutions were evaluated in a sprint review meeting (Wadhwa & Sharma, 2015) in which the features developed by the application developers (i.e., researchers) were presented to our *users-partners* who tested and provided feedback on them. All the review meetings were video recorded to capture the comments from the user who was encouraged to speak aloud as features were tested. The feedback collected was utilized to adjust, if needed, the user interface of the application or the feature workflow itself.
To test OGITO-*noise* in a real-world setting, we developed and tested a core version of it in three software development iterations with our *user partners* where most highly prioritized stories were implemented. Then, we applied it in such a real-world setting, i.e., we tested OGITO-noise in a workshop with participants from the planning practice to support collaborative NAP. The following subsections provide details of the evaluation framework applied and the case study selected.

4.3.3. Evaluation Framework

The evaluation of OGITO-noise aimed to gain insights into its usability and usefulness, as perceived by *end-users,* also called participants, for tasks related to NAP using a maptable. For the usability evaluation, we selected a task-based evaluation. Meaning that, during a NAP workshop, participants execute specific tasks using OGITO-noise and provide feedback about its usability by

filling a post-workshop questionnaire (see Appendix C), and participating in an open discussion. Questions were asked in lay terms to avoid bias in participation. The open discussion allowed participants to provide additional feedback, e.g., how they perceived the tool and what they would suggest to advance it.
The tasks carried out by workshop participants were a) mapping noisy and quiet places, b) exploration of population and institutions exposed to noise, and c) proposal and rating of noise abatement measures. For such tasks, usability dimensions were contextualized to our case study as follow:

- Effectiveness: measured by perceived completeness meaning that the map sufficiently depicts the current noise situation.
- Efficiency: measured by human effort, i.e., ease of use of the application.
- Satisfaction: evaluated the general user attitude toward the application.

To evaluate perceived usefulness, we adapted the framework proposed by Champlin et al., (2018) and Pelzer (2017) considering usefulness along the following headings: a) learning about the object, b) learning about other stakeholders, c) collaboration, d) communication, and e) consensus (see Appendix C). We omitted headings related to an outcome, i.e., the generation of better-informed plans, because our planning workshop objective was not directly related to elaborating a detailed plan for noise management but collecting local knowledge. Such local knowledge, developed in a given community and based on experience (Pfeffer et al., 2011), can inform noise action plans. We also focus on stakeholders' participation and how OGITO-noise can be used to support it. Hence, we understand the usefulness of OGITO-noise concerning its role as a mediator in the planning process rather than as an outcome facilitator (Foth et al., 2009; te Brömmelstroet & Schrijnen, 2010). Table 4-1 lists selected usefulness headings and their description in the context of OGITO-noise evaluation.

Table 4-1. Usefulness evaluation of OGITO-noise. Adapted from Pelzer (2017) and Champlin et.al (2018)

Heading	*Definition*
Learning about the object	Gaining insight into the nature of the environmental noise and how it can be addressed
Learning about other stakeholders	Gaining insight into the perspective of other stakeholders about noise
Collaboration	Interaction and cooperation among the stakeholders involved
Communication	Sharing information and knowledge among the stakeholders involved
Consensus	Agreement on problems, solutions, knowledge claims and indicators

Prior to applying this evaluation framework in a workshop with stakeholders from planning practice (*end-users*), we conducted two pilot workshops with participants from Bochum University and the University of Twente, respectively. The purpose of these pilots was to test the workshop design, e.g., time allocated for each task, tasks order, instructions for participants, and test the evaluation framework. We adjusted those aspects when needed and proceeded to conduct a workshop with *end-users*.

4.3.4. Case study

We selected the city of Bochum, Germany as the case study given the expressed interest in a maptable tool for collaborative planning and hence the accessibility to stakeholders and the public availability of modelled noise maps. Figure 4-2 presents a noise map of the Bochum city; lighter red colours represent lower levels of noise exposure, the blue colour represents the highest noise exposure level.

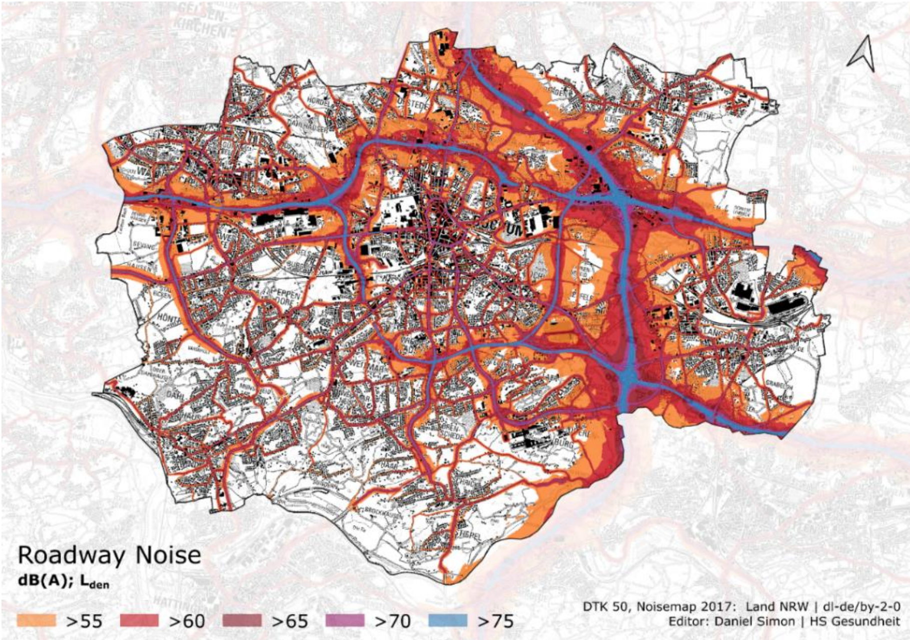

Figure 4-2. A noise map of Bochum, Germany. Source: HS Gesundheit.

End users, i.e., stakeholders from the municipality, interacted with OGITO-noise to evaluate its potential to support collaborative NAP in a maptable-based workshop setting. In this workshop, OGITO-noise was utilized to gather people's perception of the current acoustic environment, e.g., identify noisy places, and discuss measures or interventions for noise abatement (Xiao et al., 2018). To do so, the workshop followed a sequence of tasks to be executed by participants (see subsection 4.4.1).

4.4 Results

This section presents the identified tasks and workflow for a maptable-based NAP workshop, depicts OGITO-noise's architecture, dataset and main components, and reports on its usability and usefulness evaluation.

4.4.1. Identified tasks for a maptable-based NAP workshop

We collected 29 user stories that were further analysed to identify functional requirements of OGITO-noise, user groups and associated tasks executed in planning workshops supporting NAP. Identified *end user* groups were laypersons, environmental professionals, city planners, NGOs, politicians, local tram companies, city health department professionals and researchers. Identified tasks to be carried out by these user groups were clustered in five main headings as follows:

- Data exploration: to get to know the dataset via map navigation, layer management, and map symbology.
- Data analysis: to examine the current noise burden by visualizing and quantifying the intersection of modelled noise maps and the population and vulnerable institutions exposed to certain levels of noise (via spatial queries).
- Identification: to draw in the map perceived noisy and quiet places and indicate perceived noise sources and noise annoyance for noisy places.
- Intervention: to propose and rate noise abatement measures for a particular area; to rate areas that might be designated as quiet; and to explore noise-making projects and projects related to noise abatement measures.
- Collaboration: to share the outcome of a group work around a maptable when several groups participate in a workshop using several maptables or when several groups are participating synchronously and remotely.
- Data enrichment: to add local knowledge considering existing (noise/quiet) data.

Most user stories, 14 out of 29, were related to the identification tasks, four stories concerned data analysis, three stories were related to data exploration, four stories concerned intervention whereas three stories dealt with collaboration tasks and one story concerned data enrichment. Priorities given to the stories were as follows: nine were classified as *Must be*, six as *Should be*, nine as *Could be* and five as *Won't be*.

4.4.2. Workshop design

Considering the identified tasks (section 4.4.1), our workshop experience, and insights from the pilot workshops, the following design for a participatory workshop of two hours emerged in which participants conducted three main activities with a maptable: a) analysis of the current noise burden situation, b) identification of noisy places, and c) proposing and rating noise abatement measures. Two activities - introduction and closing - were also included. In the introduction, a moderator explained the purpose of the workshop and dataset used, whereas in the closing, participants were asked to provide feedback about

OGITO-noise via a questionnaire and open discussion. We excluded tasks related to the exploration noise-making projects and projects related to noise abatement measures as they were not directly related to the development of noise action plans, and it might have been challenging to obtain updated information on such projects. Also, the collaboration tasks were omitted as we envisioned a co-located and synchronous setting for this workshop, i.e., participants around a maptable. A planning researcher from our *user-partners* moderated the workshop, and one of the authors provided technical support.

4.4.3. OGITO-noise application platform, spatial dataset and layout

OGITO's architecture consists of a frontend that provides the User Interface (UI) of the application and a backend that provides services to process user input data and access to the data stored in a PostgreSQL database. This architecture (see Figure 4-3) was extended from previous work to accommodate, by-users required, analytical capabilities via API services offered by PostGraphile (https://www.graphile.org/postgraphile/). This API allowed for computing spatial queries and retrieving, on the fly, their results during a workshop session. Spatial data layers such as aerial photos or official noise maps were downloaded or consumed from German official repositories (https://www.bezreg-koeln.nrw.de/brk_internet/geobasis/index.html and http://laermkartierung1.eisenbahn-bundesamt.de); we also utilized Open Street Map (OSM; https://www.openstreetmap.org/) as an alternative background layer (see Table 4-2).

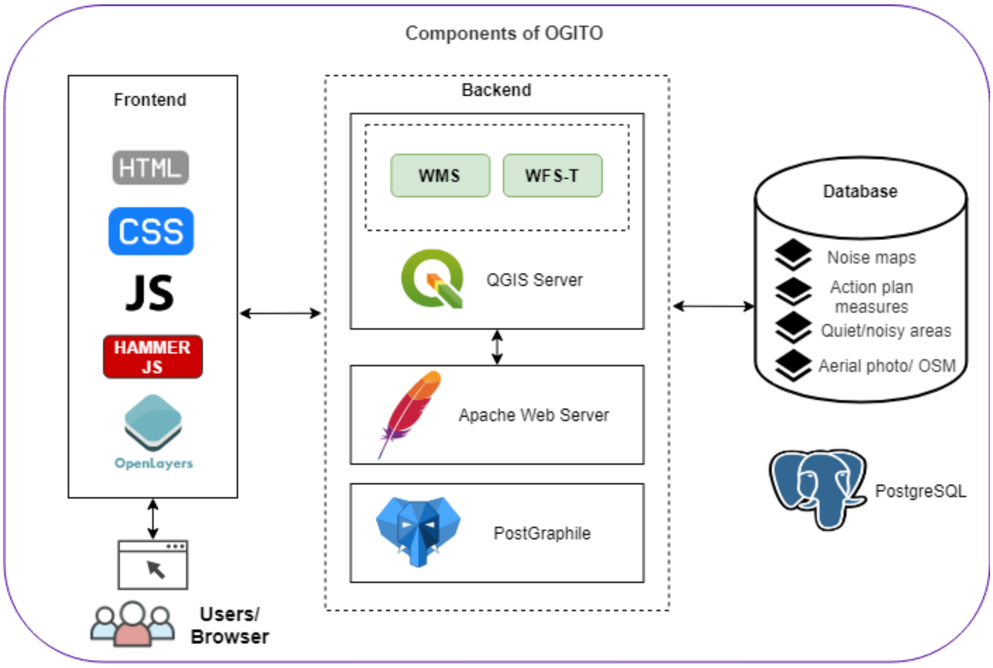

Figure 4-3. OGITO-noise's Architecture.

Spatial dataset

The spatial dataset included in OGITO-noise consisted of modelled noise maps, i.e., maps of average day-evening-night noise levels (L_{den}) and night-time noise levels (L_{night}) for streets, industries and trains and light rail trains. These modelled maps enabled users to analyse the current noise burden situation in the study area. We also included open data concerning critical infrastructure and population density. This data was used to compute on-the-fly and represent in the map institutions and population exposed to certain noise levels. Users could also generate maps of noisy and quiet places as perceived by them; and a map of noise measures, i.e., location where actions to abate noise are proposed and rated. Table 4-2 lists the spatial data included in OGITO-noise and their corresponding source.

Table 4-2. Spatial data included in OGITO-noise

Layer	Description	Source
Borders	The study area extent and its administrative division	Bochum municipality
Noise maps	Modelled strategic noise maps made mandatory by the European Directive 2002/49/EC, i.e., maps of day-evening-night (L_{den}) and night-time noise (L_{night}) levels for land transport infrastructure: roads, trains and trams, and industrial plants. Noise levels are expressed as decibels adjusted to human hearing - dB(A)	Roads, tram and industry: Bochum municipality Train: Federal rail Agency (Eisenbahnbundesamt)
Noisy places	Noisy places as perceived by participants	Empty layer, to be populated by participants
Quiet places	Quiet places as perceived by participants	Empty layer, to be populated by participants
Noise measures	Locations where participants propose and rate actions (measures) to abate noise	Empty layer, to be populated by participants
Population	Estimated total number of people per grid-cell for the study area	https://www.worldpop.org /geodata/summary?id=49977
Institutions	Critical infrastructure such as kinder garden, schools and hospitals	OpenStreetMap
Background layers	- Topographic map	OpenStreetMap (www.osm.org)
	- Digital Orthophoto	Geobasis NRW (https://www.wmts.nrw.de /geobasis/wmts_nw_dop)
	- Annotations, e.g., main places and streets names	Geobasis NRW (https://www.wmts.nrw.de /geobasis/wmts_nw_dop_overlay)
Session layers	Dynamically added layers containing the results of spatial queries	GeoJson files dynamically generated and loaded in OGITO-noise

4.4.4. Key components of the application

The OGITO-noise UI is depicted in Figure 4-4. The central component is an interactive map (1) that responds to common gestures such as pinch (to zoom in), unpinch (to zoom out), pan (to move) and rotate. Buttons and a control bar are also provided for zoom in and zoom out; and a graphical scale bar is presented at the lower-left corner of the map. The layer management (2) allows layer groups and layers to be shown or hidden; layer groups can be reordered. This component (2), in combination with the editing toolbar (4) and a symbol panel (5), also supplies tools for information retrieval and data input. Similarly, sketching tools are provided on the main toolbar (3) in combination with (4) and (5). Analytical capabilities, i.e., spatial queries to find population or critical infrastructure exposed to different noise sources are also accessible via the main toolbar (3).

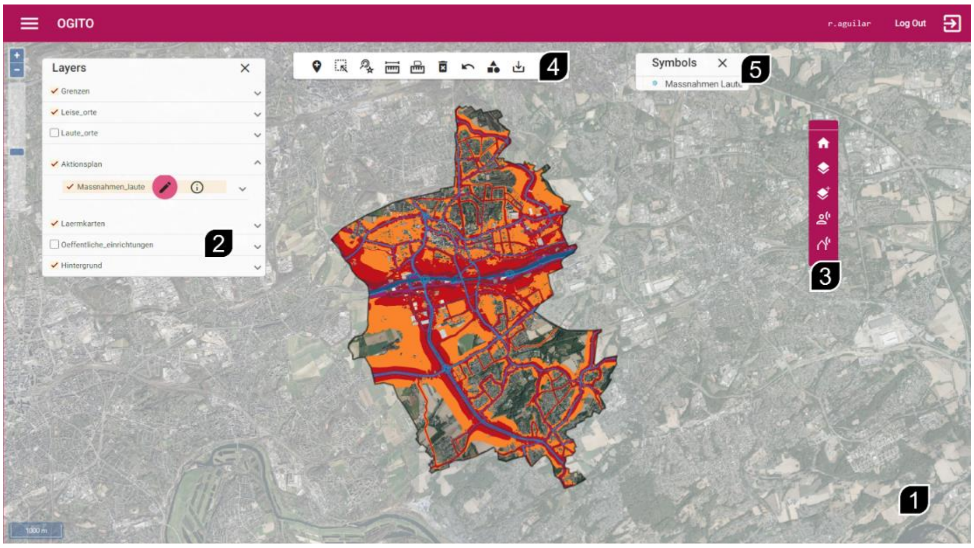

Figure 4-4. OGITO-noise interface (screenshot from application, with boxed numbers added for explanations in this chapter).

As mentioned in section 4.4.1, OGITO-noise was utilized for three main activities during the workshop with *end-users*. To analyse the current noise situation, participants displayed modelled noise maps, retrieved information from them, and quantified the population and institutions exposed to certain noise levels via on-the-fly spatial queries. To perform such queries, participants selected the noise source, e.g., roads, industries, etc. and noise thresholds, meaning the lower and upper noise level limits. For institutions, participants also selected the type of institution. The newly computed layer was added to the map. Figure 4-5 presents the modelled noise map for roads, day-evening-night (L_{den}), whereas Figure 4-6 depicts the estimated population exposed to L_{den} values between 55 and 65 dB(A); darker values represent higher number of people per grid-cell in Figure 4-6.

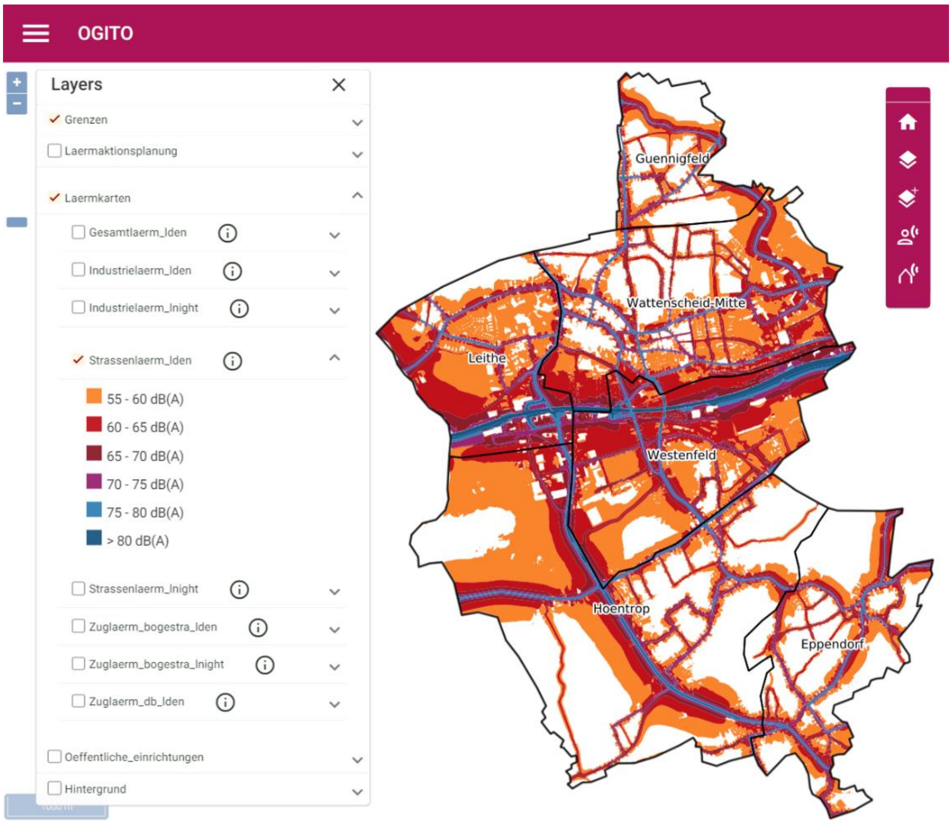

Figure 4-5. Modelled noise map for roads - day-evening-night noise levels (L_{den}) (Screenshot from application).

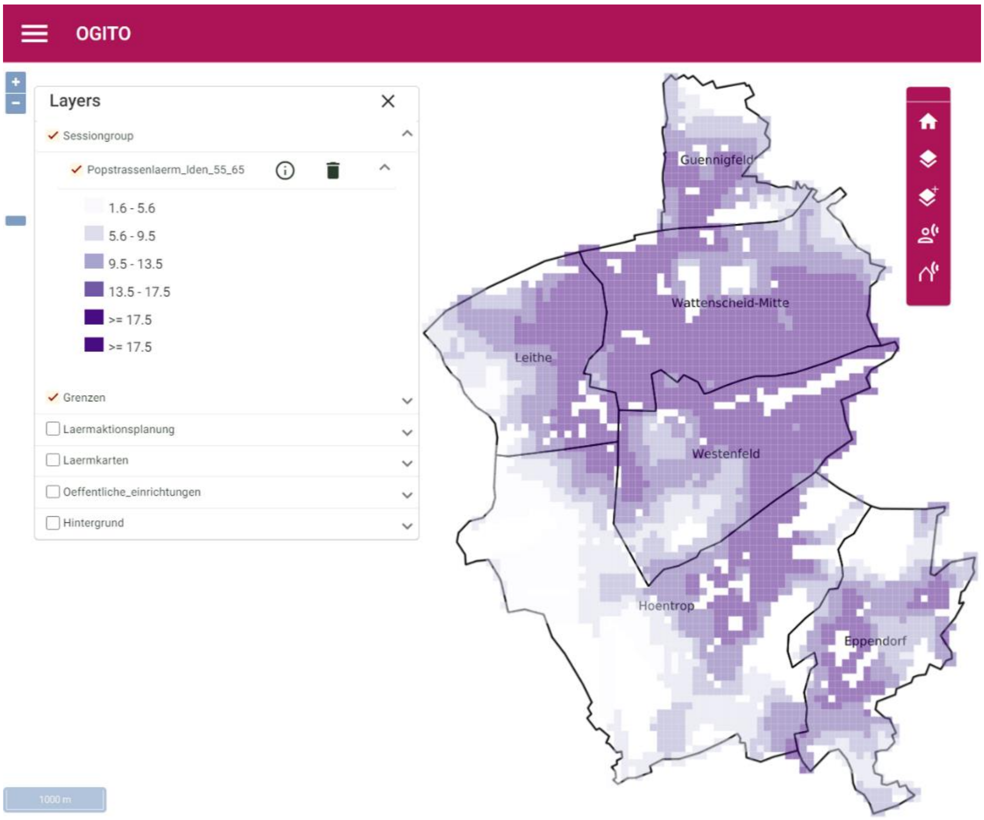

Figure 4-6. Estimated population exposed to roads noise levels (Lden) between 55 and 65 dB(A) (Screenshot from application).

The identification of noisy places enabled adding participants' perception regarding noise by identifying noisy places in the map and adding additional information. For example, sources, time, and intensity of the perceived noise. Figure 4-7 illustrates the case of a noisy place. Noisy or quiet places, could also be edited, e.g., moved or deleted.

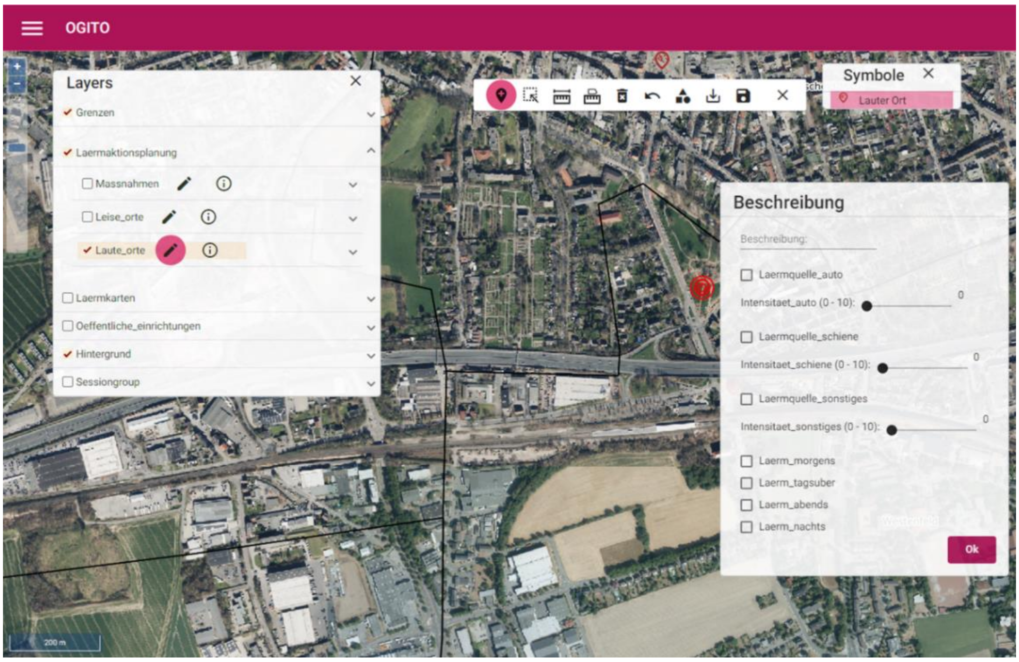

Figure 4-7. Adding an identified noisy place in OGITO-noise (Screenshot from application).

Proposing and rating noise abatement measures were performed in two steps. First, users map the location, i.e., add a point, where specific measures are desired; the application gives a set of predefined measures, but it is possible to propose others. In the second step, the selected/proposed measures can be rated to express preference. Figures 4-8 and 4-9 show the two-step process to propose and rate noise abatement measures for a particular location.

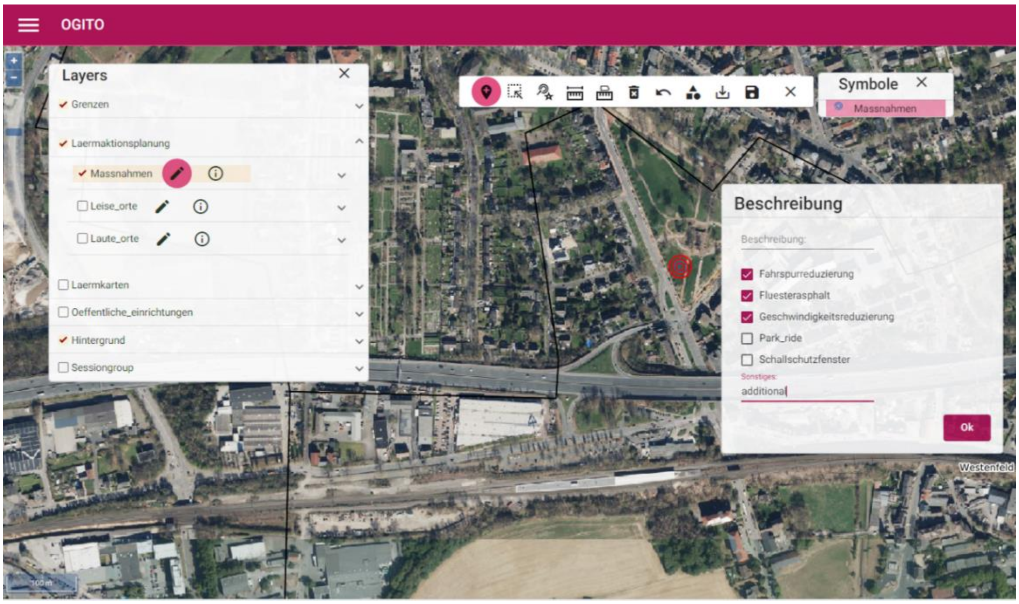

Figure 4-8. Proposing noise abatements measures (Screen from the application).

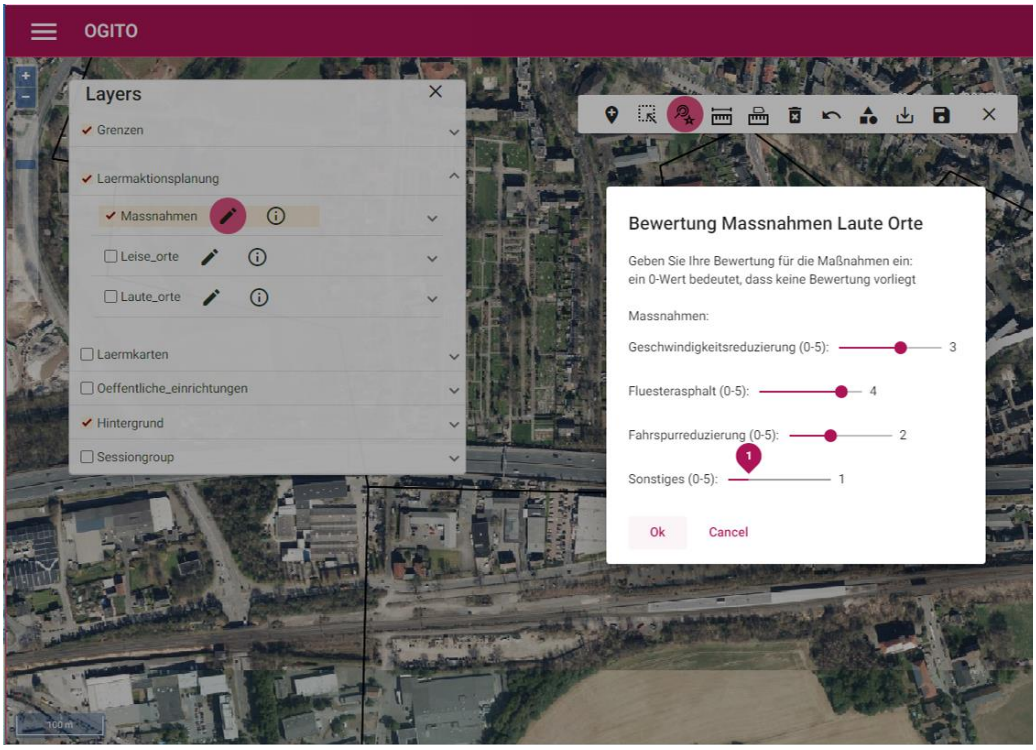

Figure 4-9. Rating noise abatements measures (Screen from the application).

OGITO-noise also allows adding sketch layers where points, lines and polygons can be drawn. However, this functionality was not included during the NAP workshop due to the limit of two hours for such workshop.

4.4.5. Usability and usefulness evaluation

Four participants from the municipality attended the workshop in the city of Bochum, where the usability and usefulness of OGITO-noise were evaluated. Workshop participants were professionals; two were involved in strategic planning, one in transport planning and the other in the environment department. Their ages ranged between 31 and 65 years old. They all had attended other participatory mapping activities before more than three times. Figure 4-10 illustrates a maptable and the participants around it during the NAP workshop.

Figure 4-10. OGITO-noise used during the noise action planning workshop in Bochum. Source: first author.

The overall response to the *efficiency* of the tool was positive. Participants found it *easy or very easy* to navigate the map and to rate noise abatement measures. However, identifying population and institutions exposed to noise and deleting elements from the interactive map was mixed evaluated, i.e., easy or neither easy nor difficult. One person found it difficult to add elements to the map.

The evaluation of *effectiveness* was also positive. Participants strongly agreed or agreed that the tool allows them to complete the majority of the tasks, e.g., to identify elements in the map, identify population and institutions exposed to noise, and to express preferences about noise abatement measures. Also, most participants strongly agreed that the tool allows adding (drawing) noisy and quiet places as identified by them; one participant neither agreed nor disagreed in this regard. On the other hand, participants were divided concerning the ease of learning of the tool. Nonetheless, the general *satisfaction* toward OGITO-noise was positive because all participants agreed or strongly agreed to recommend its use.

During the open discussion, participants were asked to provide general feedback concerning the application. Responses were clustered in three main categories: a) application, b) dataset, and c) workshop. Concerning the application, a common view among participants was that the tool is interactive and stimulates discussion; they also foresee potential applications to involve citizens. Respondents also expressed that adding additional layers on demand would be beneficial; for example, online layers from WMS (Web Map Services), locally stored layers, including CAD files, or newly computed data. Also, an annotation tool similar to those available in interactive boards was suggested. Regarding the visualization of the spatial data, suggestions included adding more contrast to the symbology for noisy and quiet areas or the inclusion of 3D views for specific locations. Concerning the workshop, participants considered the interactive maptable workshop to fit in the process of preparing decisions, i.e., before taking action to abate the noise burden. Additionally, in order to be inclusive of people with limited mobility, doing the workshop in a seated position around the table was proposed.

Questionnaire responses were markedly positive regarding OGITO-noise's usefulness. Participants agreed or strongly agreed that the application is useful to facilitate collaboration and communication among the group. Likewise, the majority of the respondents agreed or strongly agreed that they achieved consensus. Concerning learning, all participants reported learning about the nature of the noise and how it can be addressed; however, they did not agree or disagree about the novelty of their insights. Participants also reported learning about other stakeholders' perspectives regarding noise, and the perception that their own perspective was also understood. However, there was neither agreement nor disagreement among respondents regarding understanding the solutions suggested for other participants. We discuss these results in the following subsection.

4.5. Discussion

This study applied a co-design approach to develop OGITO-noise - an open interactive tool to support NAP. We adapted traditional co-design methods to a hybrid environment which is still uncommon in Human-Computer Interaction (HCI) research (Harrington & Dillahunt, 2021). Our *user-partners* remained engaged during the whole co-design process. This engagement could obey to the research orientation of our *users-partners* and the time allocated to each online meeting that was limited to two hours; other studies, in contrast, reported users' challenges to remain engaged in a remote design environment (Harrington & Dillahunt, 2021; Kennedy et al., 2021). More research should investigate whether such hybrid methods can produce similar engagement results when applied with laypersons. Such engagement is particularly relevant due to the restrictions of social distancing imposed in several countries aiming to curb the current global pandemic.

User stories were a central element in this research. Our *user-partners* formulated and prioritized them and participated in the conversation where alternative designs to satisfy the requirements that such stories expressed were discussed. This process led to the functionality of OGITO-noise that was found, by *end-users,* usable and useful, meaning that the developed tool met the users' needs. This finding supports previous work linking the utilization of user stories with the production of the "right" software that meets the "right" user requirements (Lucassen, Dalpiaz, van der Werf, & Brinkkemper, 2016); and the use of HCD approaches, e.g., iterative evaluation of design solutions, with highly usable systems (Russo et al., 2018b).

User feedback collected during the review meetings helped fine-tune the tool functionalities and identify usability pitfalls. For example, instead of multiple ratings (e.g., per participant), adding one rating to each noise abatement measure was preferred for our *user-partners* because such rating would reflect the result of the discussion among participants, hence, more suitable for group dynamics. Similarly, conducting pilot workshops provided useful insights concerning its sequence of activities. For example, the analysis of the current noise situation was put first because participants of those pilots found it more logical to start with understanding the noise as expressed in the modelled maps, and then identifying additional noisy and quiet places. As suggested, the activities sequence was adjusted for the workshop with *end-users* and worked well.

The self-reported questionnaire and the feedback gathered during the open discussion indicate that, in general, workshop participants evaluated OGITO-noise's usability positively and expressed the intention to recommend it for NAP activities. This result is likely related to our co-design approach, where users played an active role from early stages of the design process through cycles of software development and user feedback. These results reflect those of Vonk & Ligtenberg (2010), who also found that close collaboration with users led to better-accepted planning tools. Likewise, Trubka, Glackin, Lade, & Pettit (2016) reported on the benefit of iterations of software development and user feedback to achieve a highly usable system. Nonetheless, not all participants found the tool easy to learn. A possible explanation for this might be that understanding noise maps can be challenging for non-experts (Mietlicki et al., 2020; Riedel et al., 2017). Another possible explanation could be that users might need a bit of practice before being confident while interacting with touch screens, as remarked by Boulange, Pettit, & Giles-Corti, (2017). In a follow-up workshop, more attention could be paid to those aspects, e.g., explaining modelled noise maps, giving more time to familiarize with the tool and evaluating afterward.

The overall evaluation of OGITO-noise's usefulness was also substantially positive in the five headings selected. The undoubted benefit was perceived in the communication and collaboration headings. These scores and the highly positive response on learning about the object at stake and about other stakeholders' perspectives are consistent with previous studies on the use of maptables (Pelzer, Arciniegas, Geertman, & de Kroes, 2013; Shrestha, Flacke, Martinez, & van Maarseveen, 2018). On the other hand, we surmise that the neutral response concerning learning about noise abatement measures relates to participants' previous knowledge because they were already familiar with such measures. Additional workshops with, e.g., citizens may provide more insights into the ability of our application to learn about noise abatement measures by lay people.

4.6. Conclusions and future work

The purpose of the current study was to co-design and develop an Open Geospatial Interactive Tool coined as OGITO-noise and to explore to what extent it can be usable and useful in supporting collaborative NAP. Although the number of participants in our evaluation prevents us from drawing statistically-solid evidence on the usability and usefulness of such a tool in practice, our results have shown how HCD and Agile methods can be utilized to involve users in a co-design process to develop an open application that was - according to the self-reporting of users - usable and useful in supporting NAP with maptables. This result makes us argue that our approach is meaningful towards developing usable and useful PS tools. Furthermore, our hybrid methods, i.e., remote co-design meetings and face-to-face testing were necessary during a pandemic but can be used when dealing with geographic or resource limitations. We also contribute to the NAP arenas by recommending a workshop structure, based on our findings, for stakeholders' engagement in participatory activities. Future work directions might focus on the co-design process, e.g., the inclusion of *end-users* from the beginning of such process, and advancements in the OGITO-noise tool such as 3D visualization, and recommendation of noise abatement measures at specific locations given certain conditions, e.g., population or critical infrastructure exposed to higher levels of noise. Also, functions for synchronous remote settings could be added, i.e., explicit management of remote collaboration given the potential of the OGITO-noise web platform for this configuration and the increasing demand for e-participation (Heijne et al., 2018).

5. An Open Geospatial Interactive TOol - OGITO: design, implementation and setting up

5.1. Introduction

Software specifically designed for maptables PSS is still rare, and if so, it has limited analytical capabilities to support spatial planning processes (González et al., 2020; Pettit et al., 2020). A central objective of this research was to produce a digital tool to support spatial planning processes where maptables are used as planning support tools. The developed tool was coined OGITO – Open Geospatial Interactive Tool.

The design and implementation of OGITO was an iterative process that started with a core set of user requirements (see chapter 2) that drove the selection of its architecture, Graphical User Interface (GUI), and main functionalities. As a result of the case studies addressed during this research, see chapters 3 and 4, additional requirements emerged which shaped the current version or tool.

For completeness, the initial set of selected user requirements is listed below:

- Interoperability: the tool has easy integration with typical GIS applications and formats and portability of the resulting analysis.
- Intuitive interface: the GUI looks and works similarly to a mobile phone or tablet, e.g., a simple interface with oversized buttons.
- Touch-gesture support: the interaction with the tool can be fully done with touch gestures. In particular, operations in the interactive map such as zoom in, zoom out, move and rotate can be done with gestures such as pinch, unpinch, pan and tap.
- Web-based: the tool is available online.
- Open-source: the tool is Open-source software, implying that the source code can be freely modified, extended and redistributed.
- Data collection: the tool accommodates the addition of information to the map concerning the issue at stake, e.g., markers (points), lines or areas.
- Sketching and adding notes: the tool provides free-hand drawing and adding text notes on the map.

The requirements listed above configured a basic version of the software product with enough functionality to attract intended users and validate the research concept. They were selected based on previous experience in conducting and participating in maptable-based planning workshops.

This chapter starts with an overview of OGITO's architecture. Then, it depicts the front-end components created during OGITO's GUI development and describes the back-end components and the Database Management Server. After explaining how to set up an OGITO project, this chapter concludes by providing reflections and recommendations concerning software design and implementation choices. Terms application, and tool are used in the text interchangeably.

5.2. OGITO's Architecture

OGITO's GUI differs from traditional desktop applications GUI because its design supports touch gestures and includes more buttons and minimal text input requiring a (digital) keyboard. A web platform provides the necessary flexibility to implement such GUI.

An essential user requirement was an easy mechanism to store the geospatial data produced during planning workshops to be reused, later on, in popular GIS software, which means that the data produced can be interoperable, e.g., via standard GIS formats that preserve coordinates. For this reason, we selected a web map server that implements WFS-T (Web Feature Service Transaction), enabling users to edit geospatial content via a web browser. WFS-T can be implemented on different data sources with different file formats, e.g., shapefiles or spatial databases. This approach provides flexibility because the data source is loosely tied to the WFS-T.

Figure 5-1 illustrates OGITO's final architecture extended from a previous version (see chapter 3) to support on-the-fly spatial query calculation. A short description of each component of this architecture follows, namely a) front-end that provides the GUI, b) back-end that offers the necessary web and map services and the database application interface (DB API), and c) the Database Management System (DBMS).

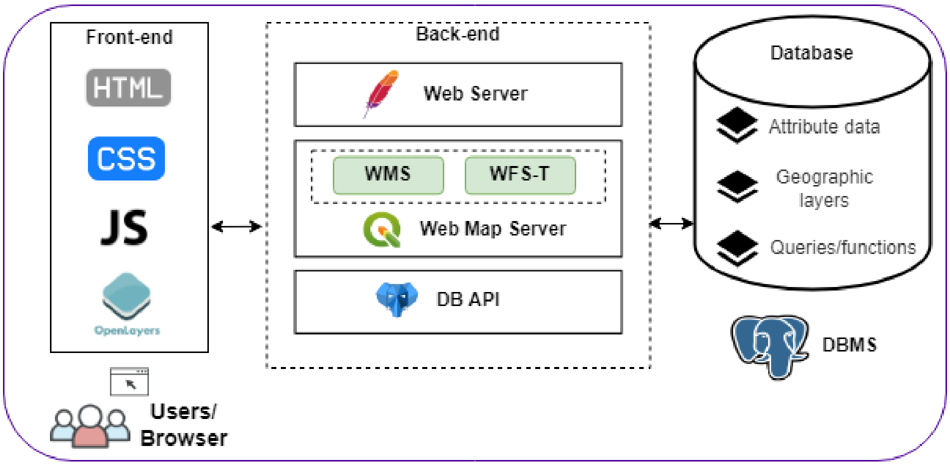

Figure 5-1. OGITO's Architecture.

5.2.1. Front-end

OGITO's front-end provides a GUI designed as a Single Page Application (SPA) that works inside a web browser and displays dynamically added content via user interaction. We used the Angular framework to develop OGITO's front-end. This framework was selected because it had a broad and active community as revealed in the Stack Overflow trends (https://stackoverflow.com/). Figure 5-2 illustrates the components and services implemented to develop OGITO's front-end. A short description of each of them follows.

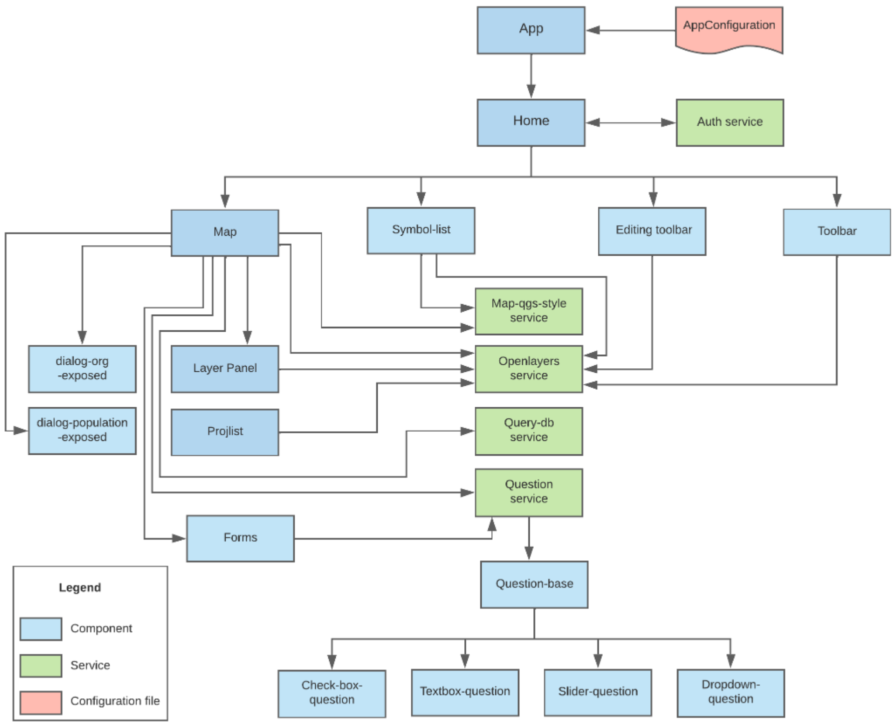

Figure 5-2. OGITO's front-end: components and services.

Components:

- *App*: the application root component with the navigation links. Global variables and settings are stored in a configuration file.
- *Home*: The entry point to the application, including authentication. After a user is logged in, it gives access to the OGITO layout described in section 5.3.
- *Map*: encapsulates all the interactive map functionality and communicates with other components to display dynamic content such as the query results. The map responds to touch gestures, as explained in chapters 3 and 4. Its interaction with other app components is done via a) parent-child events, e.g., with the layer panel; and b) services such as OpenLayers or Map-qgs-style.
- *Layer panel*: involves the functionality related to the layer management, namely: showing/hiding layers, reordering groups, starting the editing mode for a layer, or the identifying mode, i.e., retrieving information of the elements in the map.

- *Projlist*: provides a list of the projects accessible in the application. The interactive map's content and specific functions are tailored to the project selected. For example, the tool to rate noise measures is only available for specific NAP–related layers.
- *Symbol-list*: offers a simple manner to indicate the class of an element. A user selects a symbol by clicking a button before adding a new element to the map; automatically, the new element adopts the class associated with the selected symbol. With this approach, we aimed to favour buttons instead of the keyboard, e.g., to specify the element class.
- *Editing-toolbar*: includes tools for adding, editing (moving), deleting elements from the map and saving changes. It is also possible to undo (editing) actions. Depending on the project selected, proposing and rating noise measures are also available in this toolbar.
- *Toolbar*: it is the main toolbar and enables users to go to a predefined zoom area, show or hide the layer panel, add sketch layers, and find populations and organizations exposed to noise.
- *Dialogs*: the dialog-population-exposed and dialog-org-exposed are utilized to present a summary of the query executed. The first provides the share of the population exposed to the levels and source specified in the query, and the second presents a table with the number of institutions exposed to the levels and source specified in the query classified by the district.
- *Question-base:* is a base class utilized in dynamic forms to adjust the input elements, e.g., label and input control type dynamically. Using this class as a template, we specified four subclasses:
    - *Check-box-question*: enables input data through a check-box.
    - *Textbox-question*: enables input data via a (digital) keyboard.
    - *Slider-question*: enables input data using a slider.
    - *Dropdown-question*: enables input data using a dropdown control, e.g., a list.

Services:

- *Openlayers*: it is the central service that components utilize to communicate among them. It relies on observables that components "observe" via subscriptions (https://angular.io/guide/observables).
- *Map-qgs-style*: maps the QGIS style defined in the QGIS project to a style definition that is understandable in OpenLayers. This is necessary for the layers accessible via WFS-T.

- *Query-db*: performs query requests to the DB API considering the user input and returns their result.
- *Auth*: provides authentication and access management to the application via the Auth0 platform (www.auth0.com).
- *Question*: set and retrieves the forms used during input data. For each layer it configures a form to enable users add attribute information when adding geographic elements.

5.2.2. Back-end

Web Server

A web server enables the user to view OGITO's content by processing the requests triggered by the web browser utilized to access this application. QGIS Server also requires a web server to publish the geographic data. We selected the Apache HTTP server (https://httpd.apache.org/) as a web server because it has been an open-source project available for a long time. With many users, its documentation is comprehensive, and the author had previous experience with it. Also, the documentation to install the QGIS Server under Apache was already available.

Web Map Server

QGIS Server (https://docs.qgis.org/3.16/en/docs/server_manual/index.html) was selected as a web map server because it processes QGIS projects publishing the geographic layers specified in those projects. This manner accommodates an easy integration with typical GIS applications and formats and the portability of the data collected during maptables-based workshops. Also, the QGIS Server, in contrast to GeoServer (http://geoserver.org/), offers WMS services without explicit specification of layer styles used to control the appearance of the geospatial data rendered. This reduces the configuration effort during map services publishing.

We configured two map services in the QGIS server: WMS and WFS-T. WMS was utilized to retrieve layers that were not intended to be edited and to retrieve the legends shown in the layer panel. WFS-T enabled users to edit layers, e.g., add facilities (Musrenbang case – see chapter 3) or noise locations (noise action planning case – see chapter 4).

Database Application Programming Interface (DB API)

The DB API enabled the application to execute spatial queries in the DBMS and retrieve their results. PostGraphile (https://www.graphile.org/postgraphile/) was selected to implement the DB API because it offers a rapid implementation of such a component; it has specific plugins to deal with spatial objects and can detect changes in the database scheme without restarting the DB server. Also, the spatial queries dealt with data already available in the database, and no other data was needed to be sourced from third parties, e.g., via Python scripts.
A reverse proxy was configured to enable PostGraphile to receive requests on the same OGITO's URL. This reverse proxy was implemented in the Apache web server already installed. It was required to address the same-origin security policy (https://www.w3.org/2001/tag/2011/02/security-web.html).

5.2.3 Spatial Database Management Server (DBMS)

PostgreSQL was selected as DBMS because it explicitly handles spatial objects, it is a mature open-source project, and the author had previous experience with it. PgAdmin (https://www.pgadmin.org) was utilized to access the PostgreSQL server and create a spatial database to store a) geographic layers to be edited by participants during workshops and b) layers required to explore the problem at hand, e.g., modelled noise maps levels.
We also defined datatypes and functions to perform the spatial analysis operations. For example, to assess the population exposed to certain noise levels from specific noise sources (chapter 4), it was required to define PostgreSQL functions that PostGraphile enabled as DB API requests. Likewise, the quantification of institutions exposed to certain noise levels from specific noise sources entailed the definition of PostgreSQL functions for each kind of institution and noise source.

5.3. OGITO layout

OGITO's GUI is intentionally simple to prevent the complexity that more advanced mapping capabilities and interactivity would add, resulting in a reduced application to be used by non-expert users (González et al., 2020). OGITO-noise layout (see Figure 4-4) was built on OGITO (Musrenbang case - see Figure 3-4). It comprises five components, namely 1) interactive map, 2) layer panel, 3) main toolbar, 4) editing toolbar and 5) symbol panel. Details of each component and main functions provided by the application are given in section 4.4.4.

5.4. How to set up an OGITO project

OGITO requires a preparation phase before its use in a planning workshop. In this phase, the dataset is prepared and the QGIS project enabling the geoservices is configured. Preparing the dataset entails, for example, storing geographic layers, creating empty layers to be edited during workshops, configuring access in the DBMS if required and gathering information such as URL and metadata of geoservices to be used, e.g., OSM or public services that contain information of interest for the planning issue at hand, and are openly available. The QGIS project specifies layers groups, layers style and services for each of them. QGIS Desktop is utilized to create such a QGIS project. PgAdmin (https://www.pgadmin.org/) is used to create a PostgreSQL spatial database containing the geographic layers, and the functions that will become available as spatial queries through PostGraphile. Datatypes required to retrieve spatial queries results were also created via PgAdmin. In addition, the QGIS project must be accessible to QGIS Server; meaning that the QGIS Server can *serve* this project and access all the data sources that it refers to, e.g., files, databases or external WMS services. Figure 5-3 shows the relation of QGIS Desktop, QGIS Server, OGITO, PostgreSQL and PostGraphile during the preparation and execution phase.

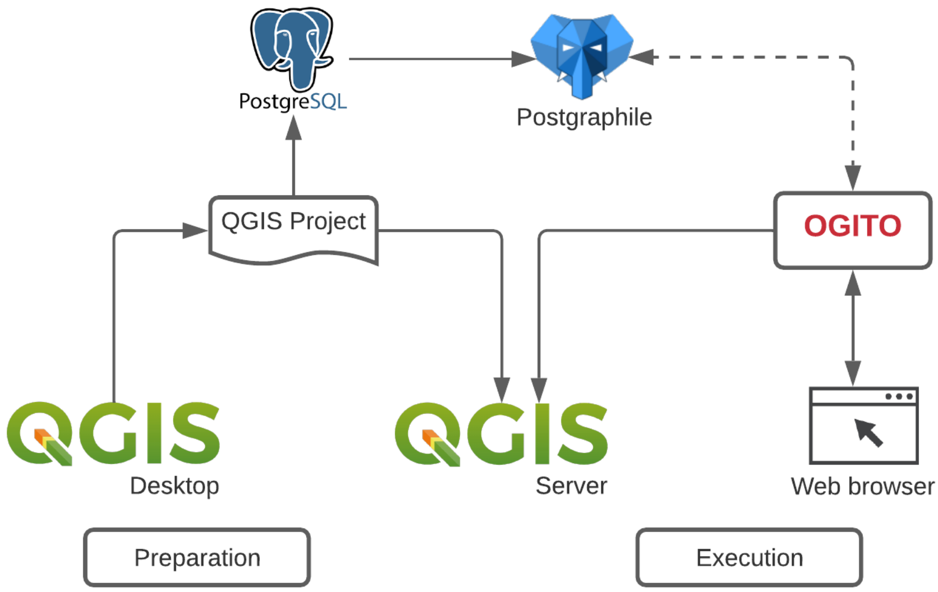

Figure 5-3. . How to use OGITO: preparation and execution phases.

5.5. Technical reflections and recommendations

The name OGITO was inspired by the Indonesian words 'Oh Gitu' which means 'Oh, I got it' or 'Okay, I understand' (Akbar, Flacke, Martinez, Aguilar, et al., 2020). Such words reflected one of the aims of this research, to develop an easy and straightforward tool that satisfies its intended user requirements. In this regard, its usability and usefulness evaluation was generally positive (see chapters 3 and 4).

There are significant changes between OGITO's versions. We aimed at a lower entry application that non-expert users could set up. Hence, with the first version, we opted for files to store spatial data (see chapter 3). This approach worked well for the context of use considered – village plan development for the Musrenbang process. However, as in the NAP case study, it did not scale when spatial queries were needed. Therefore, to accommodate the scaling, we opted for Postgres as a DBMS and PostgGraphile to implement the DB API. This adjustment adds to OGITO's innovative character because its geoprocessing capabilities of a) drawing on the map, b) adding or editing features and their attributes, and c) adding new layers are still uncommon or limited in web platforms (González, Kelly, & Rymszewicz, 2020). Nonetheless, there are opportunities for its advancement. We elaborate on these opportunities, reflect on the development challenges and provide future work directions in the following list:

- Future versions of the tool can address feedback collected during the last case study (see chapter 4), for example:

  a) Different ways of saving changes in sketch layers and WFS-T layers: sketch layers are downloaded as GeoJSON files, whereas the WFS-T are stored in the database. We recommend storing the sketch layers in the database to harmonise the way of saving changes.

  b) Adding WMS layers dynamically: adding WMS layers on-the-fly will give more flexibility to the tool because users can extend the layer dataset available in the tool during a maptables-based planning workshop. Nonetheless, the speed of the application might be affected because of the information retrieval and bandwidth available on site.

- Documentation of open-source software is sometimes suboptimal as previously remarked by Yap et al., (2022). This can follow the voluntary basis in which considerable work is done, and the orientation of financial resources to develop software features, but its proper documentation receives scant attention. However, clear and straightforward documentation is crucial to install and configure specific packages such as the QGIS Server. Such documentation can provide proper guidance and save work hours due to inexperience or lack of knowledge in specific areas directly unrelated to software development, e.g., rewriting rules in web servers. Nonetheless, the author is grateful for the 'free' and enthusiastic technical support from the QGIS community. In return, the author has contributed to the QGIS Desktop and the QGIS Server documentation and translation.

- A limitation encountered during OGITO's development was the inability to compensate for the support offered by the technical advisor with vast expertise in Angular. This advisor supported the choice of such a programming framework but, due to work relocation, continued collaborating more loosely and remotely. This made the software development more challenging.

- Future work might explore alternative frameworks to implement OGITO's front-end. For example, VUE is gaining traction given its simplicity and lightweight (Freeman, 2019). Also, the use of the NGINX HTTP server (https://nginx.org/) as a web server with a QGIS Server could be explored. Such an approach has been recently documented (https://docs.qgis.org/3.22/en/docs/server_manual/getting_started.html.

In this chapter, we briefly elaborated on technical aspects of OGITO, i.e., its architecture, layout and how to set up an OGITO project. We also reflected on technical aspects and provided recommendations. Since OGITO is a crucial contribution to this research, we also reflect on it from the research perspective in the conclusions chapter.

6. Synthesis

6.1. Introduction

The central objective of this research was to conceptualise, design and implement an interactive, open-source PS tool for maptables that fosters stakeholder interaction and engagement in collaborative spatial planning processes in close cooperation with intended users. From this objective, three specific objectives emerged (see section 1.4). This section first summarises the main findings for each of the specific objectives. It then turns to the main contributions of this study, its limitations, and recommendations for future research. It ends with a reflection on the research process.

6.2. Summary of main findings

6.2.1. Objective 1: To conceptualize, with its intended users, a PS tool for stakeholder engagement in collaborative planning processes.

This objective focuses on conceptualising a PS tool that exploits maptable capabilities while providing spatial analytical functions to better support planning and decision-making processes. In order to achieve this objective, we explored general user requirements of potential user groups from three sources: literature review, semi-structured interviews, and observations from previously attended maptable-based workshops. Non-functional and functional requirements were elicited and expressed as user stories (see section 2.4.2). Non-functional requirements described the quality attributes of the tool. Specifically, our interviewed users anticipated a PS tool that is interoperable with an intuitive interface and gesture support, web-based, open-source, transparent, modular, and adaptative to the planning phase. The functional requirements referred to specific capabilities of the PS tool, namely a) data collection via adding elements to the map, b) free-hand drawing, c) 3D visualisation, d) impact assessment, e) scenario analysis, and f) multi-criteria evaluation.

User requirements were translated into a tool conceptualisation consisting of three main building blocks supporting mapping, spatial analysis, and space-time settings. The mapping support component offers an interactive map as the central component, managing geographic data, i.e., geographic layers and data input. The analysis support component provides standard capabilities for planning problems and specific functions tailored for specific cases. Those specific functions can be established through a system design process (Sluter, van Elzakker, & Ivánová, 2017). The space-time component makes available the required capabilities to accommodate stakeholder participation in the two settings our respondents found relevant: co-located synchronous and remote asynchronous. This generic conceptualization covers the support functions expected from a PS tool (Punt, Geertman, Afrooz, Witte, & Pettit, 2020); on top of it, specifics of different solutions might be established as a result of a particular PS tool design (Sluter et al., 2017).

The mapping support provides functionality comparable to an annotated online map (Ramasubramanian & Albrecht, 2018) in which users can explore the geographic information presented in a maptable and add new information. All the interaction with the map is done via touch gestures. Putting the map as a central element of a system and enabling its use via touch gestures is a contemporary approach (Champlin, te Brömmelstroet, & Pelzer, 2019; Eikelboom & Janssen, 2013; Pelzer, Arciniegas, Geertman, & de Kroes, 2013; Pettit et al., 2020). It also supports the importance of geo-visualisation, which is considered a success factor of a PS tool (Jiang, Geertman, & Witte, 2020).

We encountered that the spatial analytical capabilities required by our intended users are linked to the stage of the planning process being addressed. No advanced spatial analysis was required at the early stages or while framing a problem or raising awareness. When applicable, demanded analytical capabilities focused on impact assessment of proposed interventions via indicator analysis. These findings, underscore the importance of understanding what user needs and support evidence from previous observations stating that, in general, there is a mismatch between tools envisioned by suppliers and users wishes; generally users want more straightforward tools (Geertman, 2017; Hewitt & Macleod, 2017).

This research also revealed that, in general, different user groups of our PS tool preferred to collaborate in a co-located, i.e., face-to-face and synchronous setting. This preference could follow the characteristics of the planning process they address, which often involved a small number of stakeholders gathering around a maptable. Also, the complexity associated with synchronous-remote settings, e.g., video or chat capabilities, and the discussed geospatial content pose difficulties for group communication. This finding, somewhat surprising, challenges previous studies in which the need for different space-time settings

for collaboration is often mentioned (Benbunan-Fich, Hiltz, & Turoff, 2003; Isenberg et al., 2011; MacEachren et al., 2005; Palomino, Muellerklein, & Kelly, 2017; Sun & Li, 2016). Nonetheless, two main settings in planning arenas, remote asynchronous and co-located synchronous, are regularly reported in applied studies. The first is utilised to address stakeholders at low participation levels, e.g., to collect people's preferences or local knowledge. In contrast, the second is applied when a significant stakeholders' involvement is pursued (Heijne et al., 2018). Approaches addressing the other settings, i.e., remote and synchronous and co-located and asynchronous collaboration, are seldom seen (Fechner, Wilhelm, & Kray, 2015; García-Chapeton, Ostermann, de By, & Kraak, 2018; Hogräfer, Grønbæk, Schulz, Puschmann, & Knudsen, 2022). Our results confirm the preferred setting for small group work collaboration in spatial planning processes.
To conclude, when addressing the conceptualisation of a PS tool presented in Chapter 2, it became evident that the requirements listed in the literature did not necessarily match those elicited with the intended users. They, in general, want simple, transparent, fast-to-setup, interoperable, and affordable tools that aid in their planning tasks. This finding corroborated previous insights regarding the mismatch between what researchers and developers of PS tools offer and what users need (Geertman, 2017) and remarked on the importance of involving users during PS tool conceptualisation to find out what is needed (Russo, Lanzilotti, Costabile, & Pettit, 2018).

6.2.2. Objective 2: To design and develop a PS tool for stakeholder engagement in collaborative planning processes in collaboration with its intended users.

This objective focuses on co-designing and developing a PS tool with its intended users. To achieve this purpose, we enquired about a suitable application platform to accommodate a basic version of the previously conceptualised tool and how to incorporate intended users into the design and development process. We explored the suitability of stable, mature open-source desktop GIS platforms. We concluded that their functionality did not suit maptables well because their GUI, i.e., menus and dialogues, is single-user-oriented with limited gesture support. A web platform was chosen to develop the PS tool given its flexibility in GUI design, e.g., more oversized buttons, minimal text input, draggable elements, and gesture support. A web platform can also accommodate, theoretically, remote group work settings, allowing a broader audience to participate. This feature gained attention after many countries imposed restrictions, e.g., group meetings and travels, to limit the spread of the covid-19 disease.

OGITO's platform, described in chapters 3, 4 and 5, integrates well-tested and widely accepted (geospatial) software components in their three central elements: front-end, back-end, and database management server. The front-end allows the development of the GUI and includes Angular as a development framework with HTML, CSS, JavaScript, and specific geospatial libraries such as OpenLayers for map visualization. Initially, the back-end consisted of a QGIS Server as the Geoweb services provider (OGC WMS and WFS-T) implemented on an Apache webserver. The back-end also incorporated a Database Application Interface (DB API) implemented in PostGraphile to address requirements that emerged during the second case study. Such DB API was necessary to provide on-the-fly spatial queries. Likewise, geospatial data management evolved from standard file formats to a spatial database management server. In other words, in our first case study (see chapter 3 - Musrenbang), we aimed to design an application that non-expert users could quickly adopt; for this reason, we chose standard format files to store the geospatial data. Therefore, we skipped a DBMS because it was unnecessary to implement the functionality required by users, and it would have added complexity to the setup. This approach worked well for the Musrenbang case study but did not allow for more complex operations such as on-the-fly spatial query computation. Such computation was a requirement of the second case study that addressed noise action planning (NAP - see chapter 4). OGITO's architecture is adjustable to a certain extent. Some components, such as the web server, DBMS or GUI framework, can be quickly replaced without affecting the front-end component. In contrast, the front-end utilizes specific no-standard functions of the QGIS Server, which makes OGITO depending on both the QGIS Desktop and QGIS Server.

Overall, OGITO's platform integrated broadly tested (geospatial) software components. For example, Angular was supported by Google and had a broad developer community. Likewise, Openlayers is well-accepted in the geospatial community. We encountered, however, that whereas the QGIS Desktop was widely used, the QGIS Server was still in an adoption phase, meaning its expert users were scarce, and the documentation was incomplete. Nonetheless, the impact of these shortcomings on the development phase of our PS tool was minimized due to the technical support received from the QGIS developer community.

We engaged in two co-design processes to elicit and address user requirements of two different case studies. Both approaches involved understanding user requirements and the context of use and producing and evaluating design solutions. We combined Agile and HCD principles to minimise the risk of producing a tool that does not meet user requirements and, therefore, would not be usable or useful. We utilised Agile to deliver functionality in short periods and HCD to consider the central role of the user perspective as a mechanism to achieve high usability of interactive systems. In the first case study (OGITO Musrenbang - see chapter 3), we involved a focus group composed of representatives of the intended users of the tool. They were professionals from the same research organisation and had collaborated on similar research projects. The user perspective was considered during review meetings where working prototypes were presented. Focus group feedback about such prototypes helped improve the tool functionality and usability, e.g., more natural interaction in the designed workflows. The whole co-design process was conducted face-to-face in regular meetings approximately every two weeks.

The second case study (OGITO NAP - see chapter 4) dealt with collaborative noise action planning (NAP), and we teamed up with a research group from Bochum University, our user partners of the tool. The co-design methods were adjusted to a hybrid environment, i.e., online meetings and face-to-face evaluation workshops. This tweaking responded to the restrictions on social distance imposed in several countries to curb the spread of the covid-19 disease. Our user partners engaged in a fairly structured co-design process, which included a) user stories writing workshop, b) online survey, c) user stories prioritisation workshop, and d) review meetings. The user stories writing, online survey and prioritisation workshop enabled us to identify essential user requirements of the tool and gather user feedback about proposed workflows - specified in low-fidelity prototypes. The review meetings, monthly conducted online, served to test working prototypes and intuitively explore their usability.

Our *user partners* engaged during the entire co-design process in both case studies. We did not encounter any roadblocks in the remote design process, as other studies have reported (Harrington and Dillahunt, 2021; Kennedy et al., 2021). A possible explanation for the engagement of our *user partner* might be given by their shared interest in developing such a PS tool and research orientation and closeness to the research group due to previous collaborations. Also, the two-hours time allocated to the online meetings might have played a role in such an engagement. Nonetheless, further research is necessary to explore whether such engagement can be achieved in co-design processes with laypersons and *end-users* of the PS tool.

6.2.3. Objective 3: To implement a PS tool and evaluate its usability and usefulness during spatial planning processes in two case studies.

This objective deals with implementing and evaluating the developed PS tool, coined as OGITO, Open Interactive TOol, in real-world settings, i.e., two different case studies. The guiding questions for this objective were a) what are the specific user requirements of the PS tool for the given context of use, and b) to what extent is the developed and implemented tool usable and useful in the planning processes addressed? In the following paragraphs, we respond to these points.

Case studies addressed two different contexts, i.e., differences concerning geographic region, user education and map literacy, and planning tasks. The first was situated in two Indonesian villages in Sumatra, where a low percentage of participants had a university education level and were unfamiliar with digital maps. The second occurred in Bochum-Germany, where all participants had a university education and often worked with maps. User requirements differed for these cases; a simple tool was required for the first, while more complex operations were needed for the second. This finding underscores repeated calls of other studies (e.g. Geertman, 2017; Jiang et al., 2020) that one PS tool does not suit all situations and should be tailored to the context of use. It also provides empirical evidence that working closely with users sheds light on their real needs and leads to users' reported usable and useful systems and confirms the relevance of considering the context of use as a determinant factor of a PS tool's usefulness in practice (Jiang et al., 2020).

In the first case study, OGITO was utilized to support community mapping in a budgetary process – the Musrenbang. The intended users were villagers, and their goal was to produce a map of their village and a map proposing interventions collaboratively using the maptable. User tasks entailed drawing existing facilities, roads, water bodies, land use and borders, and any conflict areas. The complexity of these tasks was relatively simple because they require low spatial knowledge (Akbar, 2021). The principal user requirements to accomplish these tasks were a) simple and clean GUI that only provided the necessary functions while keeping low complexity in the interface and setup, b) menus and dialogues of the GUI interface written in Bahasa language (i.e. local language of the PS tool end-users), and c) using pre-defined symbology for geographic layers visualization and map composition. This pre-defined symbology, specified in the law, utilized Bahasa characters (Akbar, Flacke, Martinez, Aguilar, et al., 2020). In the second case, the developed tool was utilized to collect stakeholders' perceptions concerning noise-related issues in collaborative NAP. Target users were planner practitioners and researchers, GIS experts and residents. User tasks included a) analysis of the current noise situation, b) identification of noisy places, and c) proposing and rating noise abatement measures. These tasks were complex compared to those of the first case study and demanded higher spatial knowledge. The essential specific user requirements revealed during the co-design process were a) interface written in the German language (i.e. the local language of the PS tool end-users), b) identification of perceived noise places, including the intensity of the noise and its source, c) rating and adding noise abatement measures, and d) on-the-fly computation of spatial queries to quantify people and institutions exposed to noise levels.

The iterative design and development cycle in both case studies included evaluating and adjusting working prototypes until they met user requirements. Next, we implemented the developed tool in maptable-based planning workshops with real stakeholders and evaluated its usability. The evaluation was extended for the second case study to explore the PS tool's usefulness. Methods used for the tool evaluation were post-workshop questionnaires and open discussions. Before such a workshop, we conducted pilot workshops to test the workshop structure, e.g., tasks order and duration and clarity of the questionnaire. Feedback collected during those pilots allowed us to adjust elements when needed. The evaluation with real stakeholders and their pilots was entirely conducted in a face-to-face fashion.

In both case studies, participants reacted positively toward the tool for the given context of use. They generally reported positive scores in the three usability dimensions, effectiveness, efficiency and satisfaction. Users could utilise the PS tool without assistance after a short introduction to it. However, for the Musrenbang case study, a few users found it challenging to use OGITO. This difficulty could obey the community's self-reported low digital map literacy, which imposes challenges for them in managing web maps (Gottwald, Laatikainen, & Kyttä, 2016). Similarly, not all participants found the PS tool easy to use in the second case study. This observation might be related to the complexity of understanding noise maps for non-experts (Mietlicki et al., 2020; Riedel et al., 2017). In both cases, providing more time for users to become familiar with the tool might benefit their interaction with a maptable, as Boulange et al. (2017) suggested.

The co-design processes that utilized user stories extensively and the iterative evaluation of the design solutions (HCD) might explain users' overall high usability scores. Those approaches have been previously linked to producing software that meets user needs (Lucassen et al., 2016) and highly usable systems (Russo et al., 2018b).

In our second case study, users found the tool particularly beneficial for communication, collaboration and learning. These findings are consistent with previous studies that also remarked on the usefulness of maptables in collaborative spatial planning processes (Pelzer et al., 2013; Shrestha et al., 2018). We observed generally positive scores in usability and usefulness that suggest a likely link between usability and usefulness, as previous studies have indicated (Jiang et al., 2020; te Brömmelstroet, 2017a). Nonetheless, we observed that participants of the first case (OGITO Musrenbang) were more cautious in providing opinions and suggestions than participants of the second case (OGITO noise). A possible explanation is that Indonesian participants were less familiar with digital maps. In contrast, German participants were used to digital maps and had experience with planning workshops and might intend to incorporate the PS tool in their processes. Another possible explanation is the cultural difference (Santoso & Schrepp, 2019).

6.2.4. Overarching research goal

This research aimed at conceptualising, designing and implementing an interactive, open-source PS tool to support maptable-based planning workshops. To this end, we produced a generic PS tool conceptualisation that considered the perspectives of different user groups. Although insightful, such a concept is always broad, and the application development would likely take several years and more software development capacities than available for this research. Nonetheless, we developed a part of this conceptualisation. By utilising case studies for detailed co-design processes, we could elicit the specific contexts of use for the PS tool, e.g., user roles, planning tasks, phase of the planning process, etc., and the functions required to support those. Such understanding was crucial to producing a PS tool that was usable and useful for such contexts of use. The consideration of additional case studies would have, undoubtedly, contributed to enriching the software functionality and flexibility because other contexts of use would provide different and specific user requirements for the tool. The question of whether we somehow anticipated those specific requirements in the tool conceptualisation remains open.

The developed PS tool supports touch gestures in the interactive map in an intuitive manner, e.g., zoom in, zoom out, pan and rotate as users expected. However, more functionality might be included, for example, gestures with more than two fingers or a long-press. Although users reported generally positive scores regarding usability and usefulness, some users found it not very easy to learn. This means that further adjustments should be done to make OGITO more intuitive, i.e., adjust the functions that were found difficult to use or learn and provide more time for users to become familiar with the tool during planning workshops.

6.3. Main contributions

The research gap identified in this study concerned the scarcity of usable, useful and open-source PS tools that can support collaborative planning processes where maptables are utilised. Responding to this gap, we conceptualised, designed, developed, applied, and evaluated a PS tool for maptables in close collaboration with its intended users. In doing so, we produced methodological, conceptual, and technical contributions and insights that might benefit the scientific and planning practitioners communities. This section describes those main contributions and how they respond to the specific scientific gaps previously described (see Chapter 1).

6.3.1. Contributions for conceptual development of PS tools

We gained insights and provided empirical evidence in two directions. First, we produced a conceptualisation of a PS tool to support collaborative planning processes with a multitude of identified user groups. Through the research we obtained evidence about user requirements concerning must-have functionalities, spatial analytical capabilities and preferred collaborative settings utilising methods from social and computer sciences, e.g., semi-structured interviews and Agile user stories. Such a combination is rarely reported in the literature and aimed at addressing the user involvement of users in PS tool development at a very early stage. The conceptualisation laid down the basis for a PS tool development, accommodates the two main, by-users reported, preferred collaborative settings, and distinguishes standard and context/problem-specific functionalities. Second, we collected evidence showing that context specific co-designing with users led to usable and useful PS tools. Involving users in PS tool development via HCD or usability evaluation has been recommended to address usability issues of PS tools. We also contributed to the potential usefulness of the PS tool in practice by providing empirical evidence of intended users' attitudes toward our developed PS tool.

6.3.2. Methodological contributions

Our research made two main methodological contributions. First, we implemented a co-design approach that extended the iterative HCD workflow with specific collaborative planning processes as the context of use. By combining HCD and Agile methods, we exercised specific Agile methods in each stage of the HCD design workflow. In this manner we addressed both usability and rapid software development. We also incorporated planning research methods such as surveys, planning workshops and post-workshop evaluation. This combination is still uncommon. Furthermore, the hybrid fashion of our combined methods showed how HCD and Agile could be utilised to involve users in co-designing a PS tool in a remote setting (e.g., covid-19 pandemic). This approach can also be utilised to overcome geographic or resource constraints. Our co-design workflow aimed at a) improving stakeholders' participation in PS tools development by utilising a mixed-methods approach that gathered user requirements and feedback regarding the PS tool under design and development, and b) bridging the mismatch between PS tool user wishes and developers' offer.

Second, we contextualised a usability framework for PS tool evaluation. We provided a detailed usability evaluation framework that discriminated the PS tool, i.e., software, from aspects related to the model, e.g., data or indicators. It utilised the usability notion from the Human-Computer Interaction perspective that we adjusted to the context of use, i.e., problem domain, planning tasks, and user characteristics. This approach addressed usability issues of PS tools and the scarcity of studies applying HCD in planning arenas.

6.3.3. Technical contributions

This research has provided two pivotal technical contributions. First, we co-designed and developed a usable and useful open-source tool explicitly intended for maptables and incorporating analytical capabilities. This PS tool offers touch gesture support and has a GUI designed explicitly for large touch screens. It also accommodates easy access to the input data added by participants during maptables-based planning workshops. The tool's analytical capabilities enable users to generate new datasets and gain insights about the problem at stake - noise in our case study. Furthermore, as the tool is open-source, it can be extended to address other planning problems or contexts. The support offered by the developed PS tool in maptables-based workshops addressed the provision of an easy-to-use geo-visual platform that fosters engagement, e.g., communication and interaction among participants during collaborative spatial planning processes. Secondly, we provided a workable architecture of a PS tool with analytical capabilities. A detailed description of the tool's front-end, back-end and DBMS components were given. This design approach addressed the limited provision of analytical functionality of the software for maptables because it allowed for on-the-fly computation of spatial queries. It might help other PS tool developers in similar endeavours as such analytical capabilities are still uncommon in web-based PS tools.

6.3.4. Contributions to the planning community

We believe the planning community can benefit from this PhD research in three aspects. First, a set of community village maps were produced with the input of villagers captured via OGITO (our developed PS tool) in the context of Musrenbang. Those village maps were required by law and needed by the Indonesian government to determine village boundaries, decide funds for villages development, and support Musrenbang practices (Akbar, Flacke, Martinez, Aguilar, et al., 2020). Using this PS tool, the post-processing work was significantly reduced. Hence, our PS tool can be utilised in supporting community mapping processes. Second, we designed a maptables-based NAP workshop structure. It described a general workflow to gather citizens' perceptions in addressing noise burden situations, including principal user tasks. To the author's best knowledge, such a workshop structure is not yet reported in the literature and can be utilised in real-world NAP processes. With this workflow, we foresee the possibility of improving citizens' participation in planning, particularly in NAP. Third, we also promoted the usefulness of PSS tools by involving NAP practitioners in unpacking the potential of our approach, i.e., maptables as a PS tool, to address real-life issues. As a result, our intended users expressed an intention of incorporating maptables in their participatory processes.

6.4. Limitations

During this PhD research journey, we encountered some limitations that are elaborated as follows:

- User requirements for the conceptualization of the tool were derived from interviews. Nonetheless, it was performed before the covid-19 pandemic. More research is needed to generalize these users' preferences and explore how the recent covid-19 pandemic might have affected them.
- We had no separate development teams for addressing HCD and Agile methods. For this reason, we could not provide insights into the likely tension between these groups when combining those approaches.
- Workshop attendees in Indonesia were only males. Their participation could potentially introduce a bias influencing our results regarding the tool's

usability. Nonetheless, for participation, a separate workshop can be organized to provide a "safe" space where females can participate.

- Our co-design methods involved user representatives that we called *user partners*. Those user partners did not include residents. However, their deep knowledge of the context of use allowed us to design and develop a PS tool that end-users, mostly residents in the Musrenbang case, received well.
- The number of workshop participants in our second case study was relatively low. Previous studies have identified the difficulties of engaging actual user/stakeholders participants in planning workshops for research purposes. Nonetheless, given the connection of our participants with real societal planning problems, their comments and suggestions were valuable for improving the PS tool.
- The language barrier limited the evaluation of users' attitudes. The two cases addressed in this research utilized a language not spoken by the author, i.e., Bahasa or German. This barrier prevented capturing user attitudes toward the tool by the author. It was particularly relevant in the Musrenbang case because participants did also not speak English, unlike the German participants who could communicate in English. Nonetheless, members of the research team contributed by taking notes and translating any feedback from users in a different language into English.

6.5. Future directions

Co-design of PS tools is gaining popularity. This includes studies focusing on developing PS tools from the procedure perspective, e.g., co-designing indicators or data models. Studies about co-designing software applications are still uncommon (Russo et al., 2018b). For this reason, we recommend further research regarding co-design approaches of collaborative PS tools and their evaluation in applied studies with practitioners and residents. The evaluation of PS tools can also provide more insights concerning the user's perception of the usefulness of a PS tool. Some specific research directions that can extend this PhD research are outlined below:

- Revisit PS tool users' perception concerning remote collaboration: interviews to conceptualise the PS tool presented in Chapter 2 were conducted prior to the covid-19 pandemic. Participants were reluctant to engage in remote collaboration, e.g., online planning workshops. Nonetheless, the spread of the covid-19 pandemic forced societies to turn toward online methods. For this reason, it might be possible that experiencing the social distancing restrictions imposed in the context of such a pandemic altered the perception of PS tool users concerning remote collaboration. Future research could repeat the semi-structured interviews to explore whether users still prefer co-located and synchronous settings for group work collaboration.

- Application of the PS tool in a collaborative remote setting: Although it was developed as a web application, it has not yet been applied in a remote setting. Future uses of the PS tool could include its configuration for asynchronous and remote collaboration, given its geoprocessing capabilities and the rising demand for e-participation.
- Incorporating *end-users* into the PS tool co-design process: Our (hybrids) methods can be extended to *end-users* to elicit additional insights, e.g., practitioners' and laypersons' perspectives, and evaluate whether such user groups remain engaged during the co-design process. Involving regular citizens in co-design processes is relevant because they are a key stakeholders group for urban planning processes.
- Addressing people with disabilities, such as limited mobility and visual impairment: the potential of using maptables to engage people with reduced mobility emerged during our workshop with end-users in Bochum (NAP case study). Also, there is a need for accessible web maps, such as those available in OGITO’s interface, intended for visually impaired people (Hennig, Zobl, & Wasserburger, 2017). Further studies might closely examine these topics.
- Development of additional functionality: our PS tool has been used for collaborative planning in community mapping and noise action planning (NAP). Future versions of such a tool might include other functions, e.g., scenario planning or 3D visualisation, that are still unavailable or uncommon in software for maptables. Such functionality was anticipated in the tool conceptualisation (see chapter 2). Nonetheless, the development and application of any additional functionality should respond to user needs that emerge during co-design approaches.

6.6. Personal reflection

The following paragraphs present a brief reflection about a) PS tools development and sustainability, b) challenges of interdisciplinary research, and c) resilience in science in covid-pandemic.

The development of PS tools is still mostly embedded in research project contexts, sometimes disconnected from practice (González et al., 2020). This disconnection prevents their sustained advancement and uptake, which is also a concern among the Free and Open-Source Software (FOSS) communities. In this research, we collaborated with researchers and practitioners to address the disconnection between what researchers develop and what users need. Concerning the OGITO's development sustainability, as suggested by Gonzalez et. al (2020) and Wang, (2012), I envision widening OGITO's user-partners community by establishing collaboration with other research institutions, and planning agencies or industries that can support the project either with development time or financially. All parties' efforts should be coordinated to ensure contemporary services essential for OGITO's applicability and sustainability over time. Those services, as recommended by Jiang et al., (2020), should consider the context of use, e.g., needs of the planning tasks, and could be derived from co-design processes with intended users.

Societal challenges call for interdisciplinary approaches where multiple views can enrich the analysis process of those challenges. However, working in interdisciplinary teams comes with challenges. We list below some of the challenges encountered and how they were addressed during this PhD research, given the author's background in computer science and the urban planning research topic:

- Understanding the urban planning context, e.g., concepts and methods from social science, to understanding the universe of discourse of the PS tool to be conceptualised, was challenging for the author, given her background in geoinformatics. Training, e.g., planning courses and openness to new concepts by engaging with literature, helped to overcome this deficiency and enabled the author to reach an understanding of the planning jargon. This experience has broadened her vision and made her aware of the opportunities to contribute to urban informatics.

- Conceptual and analytical frameworks differ between disciplines. Terminology can have slightly different meanings in computer science and planning theory. This difference was challenging at the beginning of the research. Nonetheless, with respect, leadership and open discussions, it was possible to sort out the differences and create a 'shared' conceptual framework. Promotors' leadership provided the necessary working climate to sustain open discussions with the ultimate goal of understanding and supporting the blind spots of each research member.
- The author also acknowledges the need to understand the context of use to design a PS tool beyond the perspective of a software developer. This need means embracing the research from both sides, computation and planning; for example, understanding the nature of a planning process being addressed with the PS tool and how the tool will be used. The co-design process was constructive in this matter because users openly discussed their points of view and the rationality of their preferences.
- As a computer system engineer and researcher, the author was used to develop GIS and machine learning algorithms. However, she had not been exposed to co-design approaches with users prior to this research. For this reason, working closely with people (laypersons) and witnessing their experience using the software solution was satisfying. The moment when an elderly person expressed his gratitude because his village would finally have a map was a heartwarming experience. In other words, experiencing the implementation of OGITO in real-world settings was mind-blowing and completely worthy.

The covid-19 pandemic was an unprecedented situation for many. Our research focused entirely on the enhanced interaction that maptables offer to small groups was undoubtedly affected. Nonetheless, we exhibited certain resilience by a) adapting our regular research meetings to an online mode, b) trying and discussing alternative approaches for our PS tool, such as the integration of video conference functions next to the interactive map, and c) adapting the co-design approach to a hybrid environment where the whole design and development process was entirely conducted online whereas the evaluation was conducted in a traditional face-to-face fashion. These adjustments show how, despite the situation and initial shock due to the social distance restrictions, we pursued our main research objective that is being reported in this manuscript.

Summary

Stakeholders' participation in addressing spatial planning problems remains a significant concern among scholars and planning practitioners. The communicative approach of planning support systems (PSS) aims to facilitate stakeholders' engagement through interactive digital geospatial tools. Nonetheless, despite the growing offer of PSS, its uptake in practice is still low. The use of maptables for facilitating stakeholder engagement in planning processes is a contemporary approach that has shown benefits to the planning community regarding communication, interaction and collaboration. However, PS tools for these instruments are scarce. This research aimed at conceptualising, designing, and implementing an interactive, open-source planning support tool that fosters stakeholders' engagement in collaborative spatial planning processes where maptables, digital horizontal large touch screens, are the central support instrument. For this purpose, we formulated three objectives: 1) to conceptualise, with its intended users, a PS tool for stakeholders' engagement in collaborative planning processes, 2) to design and develop a PS tool for stakeholder engagement in collaborative planning processes in collaboration with its intended users, and 3) to implement a PS tool and evaluate its usability and usefulness during spatial planning processes in two case studies. Mixed methods from both social and computer sciences were applied. The conceptualisation is based on requirements gathered from state-of-the-art literature reviews, semi-structured user interviews, and user stories. The design and development of the PS tool with users combined HCD and Agile software development methods contextualised to collaborative planning, e.g., focus group, user stories, prototypes, and review meetings. Implementing the PS tool and its usability and usefulness evaluation utilised planning workshops, self-reported post-workshop questionnaires and open discussion.

Intended users of the tool played a central role in its conceptualisation because they validated previously elicited, from-literature, user requirements and provided new ones. The resulting generic conceptualisation comprises components for mapping, analysis and space-time support. The mapping component accommodates data exploration and input, whereas the analytical component presents standard and problem-based functions of a PS tool. The first was referred to as often used in planning workshops assisted by

maptables, and the second offers flexibility for tailored made functions according to the planning problem at stake. The space-time component deals with capabilities intended to support communication and interaction in two main settings, co-located and synchronous and remote and asynchronous. Building blocks of the conceptualisation serve as a comprehensive basis for developing a planning tool that provides interactivity and analytical support to be utilised in spatial planning processes with stakeholders.

In the first case study, the conceptualized tool was developed and tested in a participatory budgeting process called Musrenbang in Indonesia. To do so, we produced working prototypes that were iteratively reviewed with users until reaching the required functionality to be tested in such a real-world setting, i.e., with users from villages in Sumatra-Indonesia. This case study focused on providing an easy-to-use tool that provides enough functionality to capture the local knowledge to produce village and development proposal maps. Users utilized the developed tool without assistance during the planning workshop and after a brief introduction. The user-reported usability evaluation showed that the iterative development process led to a usable tool, i.e., users rated its effectiveness, efficiency and satisfaction positively.

The tool was further advanced in the second case study that addressed participatory noise action planning processes. The research on this case study started during the first year of the covid-19 pandemic, and there were strict social distance restrictions to curb that pandemic. For this reason, we combined remote and face-to-face co-design methods. We also strengthened the user role in the design process by providing low-fidelity prototypes at the early stages of the design process. In addition to usability, the perceived usefulness was also evaluated in a noise action planning workshop conducted face-to-face and assisted with a maptable. The self-reported evaluation indicated that the developed tool was found usable and remarkably useful. Users provided feedback on how to advance the tool further and expressed their intention to adopt it in practice.

To conclude, this research addressed with a systematic approach the conceptualization, design, development and implementation of a planning support tool to foster stakeholder engagement in collaborative planning processes supported with maptables. By doing so, we made contributions to the scientific, software engineering and planning practitioners communities. First, we produced a conceptualisation of a PS tool with its intended users and obtained evidence related to the link between co-designing with users and usability and usefulness of PS tools. Second, we extended the HCD workflow to include Agile methods and specific collaborative planning processes as context of use. The usability evaluation of such workflow was contextualised for PS tools. Third, we co-designed and developed a usable and useful open-source tool explicitly intended for maptables and incorporating analytical capabilities. The architecture of this tool is well-documented and available in a published scientific paper. Fourth, a set of community village maps were produced for two villages in Sumatra (Indonesia) and a workshop structure for NAP was provided. We also reflected in this dissertation about the relevance of the topics discussed, the limitations of the research and future work directions.

Samenvatting

De participatie van belanghebbenden bij de aanpak van problemen op het gebied van ruimtelijke planning blijft een belangrijk punt van aandacht voor wetenschappers en planningsdeskundigen. De communicatieve benadering van ondersteunende systemen voor ruimtelijke planning (PSS) heeft tot doel de betrokkenheid van belanghebbenden te vergemakkelijken door middel van interactieve digitale ruimtelijke instrumenten. Ondanks het groeiende aanbod van PSS, is het gebruik ervan in de praktijk nog steeds laag. Het gebruik van maptables voor het vergemakkelijken van de participatie van belanghebbenden bij ruimtelijke planningsprocessen geeft aantoonbare voordelen met betrekking tot communicatie, interactie en samenwerking. PSS tools voor deze instrumenten, dat wil zeggen maptables, zijn echter schaars. Dit onderzoek richtte zich op het conceptualiseren, ontwerpen en implementeren van een interactief, open-source planning ondersteunend (PS) instrument dat de betrokkenheid van belanghebbenden bij collaboratieve ruimtelijke planningsprocessen bevordert, waarbij maptables, digitale horizontale grote aanraakschermen, het centrale ondersteuningsinstrument zijn. Voor dit doel hebben we drie doelstellingen geformuleerd: 1) het conceptualiseren, met de beoogde gebruikers, van een PS-instrument om belanghebbenden te betrekken bij collaboratieve planningsprocessen, 2) het ontwerpen en ontwikkelen van een PS-instrument voor de betrokkenheid van belanghebbenden bij collaboratieve planningsprocessen in samenwerking met de beoogde gebruikers, en 3) het implementeren van een PS-instrument en het evalueren van de bruikbaarheid en nut ervan tijdens ruimtelijke planningsprocessen in twee case studies. Een mix van methoden uit zowel de sociale als de computerwetenschappen werden toegepast. De conceptualisatie is gebaseerd op vereisten die zijn verzameld uit literatuuronderzoek naar de 'state-of-the-art' van de technologie, semi-gestructureerde interviews met gebruikers, en 'user stories' waarin gebruikers kort hun behoeftes omschrijven. Het ontwerp en de ontwikkeling van het PS-instrument met gebruikers was gebaseerd op Human-Centred Design (HCD) en Agile softwareontwikkelingsmethoden in een context van collaboratieve ruimtelijke planning, bv. focusgroep, user stories, prototypes, en evaluatievergaderingen. De implementatie van het PS-instrument en de evaluatie van de bruikbaarheid en het nut ervan zijn onderzocht tijdens planningsworkshops, zelf-gerapporteerde vragenlijsten na de workshop en open discussies.

De beoogde gebruikers van het instrument hebben een centrale rol gespeeld bij de conceptualisering ervan door deeerder uit de literatuur naar voren gekomen gebruikerseisen te valideren en aanvullende eisen hebben te formuleren. De resulterende generieke conceptualisering omvat componenten voor het in kaart brengen van ruimtelijke fenomenen, analyse en ruimte-tijd ondersteuning. De kaart -component biedt ruimte voor gegevensverkenning en invoer, terwijl de analytische component standaard en probleemgeoriënteerde functies van een PSS-instrument bevat. De eerste wordt vaak gebruikt in planningsworkshops met behulp van maptables, en de tweede biedt flexibiliteit voor op maat gemaakte functies naar gelang van het planningsprobleem. De ruimte-tijd component heeft betrekking op mogelijkheden die bedoeld zijn om communicatie en interactie te ondersteunen in twee contexten: op dezelfde locatie en synchroon en op afstand en asynchroon. De bouwstenen van de conceptualisering dienden als een uitgebreide basis voor de ontwikkeling van een planningsinstrument dat interactiviteit en analytische ondersteuning biedt voor gebruik in ruimtelijke planningsprocessen met belanghebbenden.

In de eerste casus werd het conceptuele instrument ontwikkeld en getest in een participatief begrotingsproces genaamd Musrenbang in Indonesië. Om dit te doen, hebben we, door middel van een iteratief proces met gebruikers, werkende prototypes gemaakt tot de vereiste functionaliteit werd bereikt om te worden getest in de werkelijke praktijk, d.w.z. met gebruikers uit dorpen in Sumatra-Indonesië. Deze casus richtte zich op het leveren van een eenvoudig te gebruiken instrument dat voldoende functionaliteit biedt om de lokale kennis vast te leggen voor het produceren van dorps- en planologische kaarten ten behoeve van toekomstige ontwikkeling. Tijdens de planningsworkshop gebruikten gebruikers - na een korte introductie - het ontwikkelde instrument zonder hulp. De door de gebruikers gerapporteerde bruikbaarheidsevaluatie toonde aan dat het iteratieve ontwikkelingsproces tot een bruikbaar instrument leidde, d.w.z. dat de gebruikers de doeltreffendheid, efficiëntie en tevredenheid positief beoordeelden.

Het instrument werd verder ontwikkeld in de tweede casus die betrekking had op het participatief ontwikkeling voor een aanpak voor geluid. Het onderzoek van deze casus startte tijdens het eerste jaar van de covid-19 pandemie, en er waren strikte sociale afstandsbeperkingen tijdens de pandemie. Daarom combineerden we methoden voor collaboratief ontwerpen op afstand en in persoon. Tijdens het ontwerpproces versterkten we de rol van de gebruiker door 'low-fidelity' prototypes (d.w.z. relatief eenvoudige prototypes) aan te bieden in de eerste fases van het ontwerpproces. Naast de bruikbaarheid werd ook het waargenomen nut geëvalueerd in een workshop voor geluidsplanning, die werd uitgevoerd en ondersteund werd met een maptable in een fysieke workshop. De zelf-gerapporteerde evaluatie gaf aan dat het ontwikkelde instrument bruikbaar en opmerkelijk nuttig werd gevonden. Gebruikers gaven feedback over hoe het instrument verder ontwikkeld kon worden en gaven aan het in de praktijk te willen gebruiken.

Concluderend, dit onderzoek behandelde – met een systematische aanpak - de conceptualisatie, het ontwerp en de implementatie van een planningsondersteunend instrument om de betrokkenheid van belanghebbenden te bevorderen in collaboratieve planningsprocessen ondersteund met maptables. Dit onderzoek heeft geleid tot belangrijke contributies voor zowel de wetenschappelijke en praktijk georiënteerde gemeenschappen. Ten eerste produceerden we een conceptualisatie van een PS tool met de beoogde gebruikers en verkregen we inzichten met betrekking tot het verband tussen collaboratief ontwerpen en bruikbaarheid en bruikbaarheid van PS tools. Ten tweede hebben we de HCD-workflow uitgebreid met Agile-methoden en specifieke collaboratieve planningsprocessen als gebruikscontext. De bruikbaarheidsevaluatie van een dergelijke workflow werd gecontextualiseerd voor PS-instrumenten. Ten derde hebben we een bruikbaar en nuttig open-source instrument ontworpen en ontwikkeld, expliciet bedoeld voor maptables en verrijkt met analytische mogelijkheden. De architectuur van dit instrument is gedocumenteerd en beschikbaar in een gepubliceerd wetenschappelijk artikel. Tot slot, er is een collectie van kaarten voor de gemeenschappen gemaakt voor twee dorpen in Sumatra (Indonesië) en een workshopstructuur voor het maken van een plan van aanpak voor geluid werd verstrekt. We hebben in dit proefschift ook gereflecteerd op de relevantie van de besproken onderwerpen, de beperkingen van het onderzoek en mogelijk toekomstige onderzoeksvragen.

Appendices

Appendix A. Title and reference of papers used in Chapter 2 for the identification of shortcomings and potential requirements of PS tools.

- Interactive Marine Spatial Planning: Siting Tidal Energy Arrays around the Mull of Kintyre (Alexander et al., 2012).
- Map-Based Multicriteria Analysis to Support Interactive Land Use Allocation. (Arciniegas, Janssen, & Omtzigt, 2011)
- Effectiveness of Collaborative Map-Based Decision Support Tools: Results of an Experiment (Arciniegas et al., 2013).
- From Planning Support Systems to Mediated Planning Support: A Structured Dialogue to Overcome the Implementation Gap (te Brömmelstroet & Schrijnen, 2010).
- Tables, Tablets and Flexibility: Evaluating Planning Support System Performance under Different Conditions of Use (Champlin et al., 2019).
- Exploring Landscape Engagement through a Participatory Touch Table Approach (Conniff, Colley, & Irvine, 2017).
- Beauty and Brains: Integrating Easy Spatial Design and Advanced Urban Sustainability Models (Dias et al., 2013).
- Collaborative Interaction with Geospatial Data—a Comparison of Paper Maps, Desktop GIS and Interactive Tabletops (Döweling, Tahiri, Riemann, & Mühlhäuser, 2016).
- Collaborative Use of Geodesign Tools to Support Decision-Making on Adaptation to Climate Change (Eikelboom & Janssen, 2017).
- What Do Users Really Need? Participatory Development of Decision Support Tools for Environmental Management Based on Outcomes (Hewitt & Macleod, 2017).
- The V-City Project (Himmelstein et al., 2011).
- Using Geodesign to Develop a Spatial Adaptation Strategy for Friesland (Janssen et al., 2014).
- A Collaborative Multi-Touch, Multi-Display, Urban Futures Tool (van der Laan et al., 2013).
- SimLandScape, a Sketching Tool for Collaborative Spatial Planning (Ligtenberg, De Vries, Vreenegoor, & Bulens, 2011).
- Developing a Conceptual Framework for Visually-Enabled Geocollaboration (Maceachren & Brewer, 2004)
- Using Maptable® to Learn about Sustainable Urban Development (Pelzer, Arciniegas, Geertman, & de Kroes, 2013).
- The Added Value of Planning Support Systems: A Practitioner's Perspective (Pelzer et al., 2014).

- Towards Satisfying Practitioners in Using Planning Support Systems (Russo et al., 2018b).
- Interactive Knowledge Co-Production and Integration for Healthy Urban Development (Shrestha et al., 2017).
- SUSS Revisited: An Interactive Spatial Understanding Support System (ISUSS) for Collaborative Spatial Problem Structuring (Shrestha, Flacke, Martinez, & van Maarseveen, 2014).
- Interactive Cumulative Burden Assessment: Engaging Stakeholders in an Adaptive, Participatory and Transdisciplinary Approach (Shrestha, Flacke, Martinez, & Maarseveen, 2018).
- Simlandscape: Serious Gaming in Participatory Spatial Planning (Slager, Ligtenberg, de Vries, & de Waard, 2007).
- Enabling Interaction with Single User Applications through Speech and Gestures on a Multi-User Tabletop (Tse et al., 2006).
- Adaptation Planning Support Toolbox: Measurable Performance Information Based Tools for Co-Creation of Resilient, Ecosystem-Based Urban Plans with Urban Designers, Decision-Makers and Stakeholders (van de Ven et al., 2016).
- Augmenting Quantum-GIS for Collaborative and Interactive Tabletops (Viard et al., 2011).
- Perception and Reality: Exploring Urban Planners' Vision on GIS Tasks for Multi-Touch Displays (Vishkaie & Levy, 2012)
- Socio-Technical PSS Development to Improve Functionality and Usability-Sketch Planning Using a Maptable (Vonk & Ligtenberg, 2010).
- Planning Support System for Climate Adaptation: Composing Effective Sets of Blue-Green Measures to Reduce Urban Vulnerability to Extreme Weather Events (Voskamp & Van de Ven, 2014).
- An Emerging Trend of GIS Interaction Development: Multi-Touch GIS (Zenghong et al., 2012).

Appendix B. Questionnaire used in Chapter 3.

This survey is part of the mapping activity in Village:_________. Your participation will be a great help to us. The responses will be kept anonymous. They will be used to better understand your perception about the usability of the tool (interactive map in the horizontal surface) used in the activity. In addition, summarized data will be used in scientific articles to be published. Please complete this survey before you leave.

Thank you for your participation!

About the digital tool (interactive map on a touch table) Please answer the following questions by selecting an option on the right.	Very difficult	Difficult	Neutral	Easy	Very easy
1. How was it to navigate the interactive map (e.g., zoom in, zoom out, pan)?	1	2	3	4	5
2. How was it to draw an element in the interactive map, e.g., areas, facilities?	1	2	3	4	5
3. How was it to delete an element in the interactive map, e.g., areas, facilities?	1	2	3	4	5
4. In general, how will you rate the ease of use of the interactive map?	1	2	3	4	5
About the map. Please agree or disagree with the following statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
5. I could locate or identify my community/village	1	2	3	4	5
6. The tool allows to draw all the elements identified by participants	1	2	3	4	5
7. I feel that the produced village map represents the current situation	1	2	3	4	5

8. I feel that the produced village map is the result of everyone's ideas and inputs	1	2	3	4	5

9. How long did it takes you to learn how to use the digital tool?
¨ Too long ¨ Long ¨ Neutral ¨ Short ¨ Very short

10. How satisfied are you with the digital tool used in the mapping activity ?
¨ Very dissatisfied ¨ Dissatisfied ¨ Unsure ¨ Satisfied ¨ Very Satisfied

Part 3. About you.

This part aims to know about your personal background and experience with maps and participatory mapping activities. Please fill the questions below by selecting one of the given options.

11. Fill in your gender:
¨ Female ¨ Male ¨ Prefer not to say
12. Age group:
¨ < 18 years ¨ 18-30 years ¨ 31-50 years ¨ 51-65 years ¨ >65 years
13. Select your highest completed educational level
¨ Primary School ¨ High School ¨ Bachelor ¨ MSc ¨ PhD
14. What role do you hold in the community organization?
¨ Leader ¨ Secretary ¨ Member ¨ None ¨ Other. Please specify: _______
15. How often do you use a computer/laptop?
¨ Never ¨ Few times per year ¨ Once per month ¨ Every week ¨ Daily
16. How often do you use a map in paper?
¨ Never ¨ Few times per year ¨ Once per month ¨ Every week ¨ Daily
17. How often do you use a digital map (e.g, in a phone)?
¨ Never ¨ Few times per year ¨ Once per month ¨ Every week ¨ Daily
18. Have you participated in a group mapping activity?
¨ Never ¨ 1-2 times ¨ 3-5 times ¨ More than five times

Appendix C. Questionnaire used in Chapter 4.

This survey is part of the mapping activity in the municipality of Bochum. Your participation will be a great help to us. The responses will be kept anonymous. They will be used to better understand your perception about the usability and usefulness of the tool (interactive map in the horizontal surface) utilized in the activity. In addition, summarized data will be used in scientific articles to be published. Please complete this survey before you leave.

Thank you for your participation!

About the digital tool (interactive map on a touch table) *Please answer the following questions by selecting an option on the right hand.*	Very difficult	Difficult	Neither difficult, nor easy	Easy	Very easy
1. How was it to navigate in the map (e.g., zoom in, zoom out, pan)?					
2. How was it to draw an element in a map, e.g., noisy places, quite places, action point places?					
3. How was it to delete an element in a map, e.g., noisy places, quite places, action point places?					
4. How was it to identify population and institutions exposed to noise?					
5. How was it to rate noise measures to address noisy places?					
6. In general, how will you rate the ease of use of the interactive map?					

About the map. *Please agree or disagree with the following statements*	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
7. I could locate or identify elements in the map					
8. The tool allows to draw noisy and quiet places identified by participants					
9. The tool allows to identify people and institutions exposed to noise					
10. The tool allows to express preferences about measures to address noisy places					
11. I consider that the produced maps (noisy and quiet places) represent the current situation					
12. I could use the system without having to learn anything new					
13. I would recommend the tool for noise mapping activities					

About the activity *Please agree or disagree with the following statements*	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
14. My insight into the problem of noise and measures to address it has increased					
15. For me, the session has led to new insights concerning noise and noise measures to tackle it					
16. I now better understand the suggested solutions (concerning noise) from the other participants					

17. I now understand how the other participants view the noise problem					
18. The other participants understand my view of the noise problem					
19. There was a strong sense of group feeling during the session					
20. I was able to share my ideas and opinions concerning the noise situation and how to address it.					
21. We have achieved a shared vision about possible solutions concerning noise.					

Part 3: About you

22. Fill in your gender:
    ☐ Female ☐ Male ☐ Prefer not to say
23. Age group:
    ☐ 18-30 years ☐ 31-50 years ☐ 51-65 years ☐ >65 years
24. Select your highest completed educational level
    ☐ Primary School ☐ High School ☐ Bachelor ☐ MSc ☐ PhD
25. Have you participated in a group mapping activity?
    ☐ Never ☐ 1-2 times ☐ 3-5 times ☐ More than five times

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About the author

Rosa Aguilar is a computer system engineer originally from Venezuela, where she received her BSc. In Computer System Engineering from University Lisandro Alvarado. She holds two master's degrees, one in computer science from the University Simon Bolivar (Venezuela) and another in Geoinformatics from the University of Twente (The Netherlands).

Before joining ITC at the University of Twente as a Ph.D. researcher, she worked as a Chief Technical Officer at the Geographic Institute of Venezuela. She previously accumulated practical experience in Geographic Information Systems (GIS), remotely sensed image analysis, spatial database management, and Spatial Data Infrastructure (SDI).

Rosa was awarded an excellence scholarship ITC-UT to pursue her MSc degree which was successfully completed with a Cum Laude distinction. She remained at UT university to work as a researcher and conducted her doctoral research in Urban and Regional Planning. Her paper "OGITO, an Open Geospatial Interactive Tool to support collaborative spatial planning with a maptable" received the ITC PhD Publication Award 2021 for best scientific paper among the ITC PhD community. She also became an active member of the QGIS software community during her doctoral studies.

Rosa recently rejoined the Geoinformation and Image Processing Department at ITC. She enjoys working with communities in participatory contexts as well as developing machine learning models.

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