Habitat International 147 (2024) 103040

Contents lists available at ScienceDirect

Habitat International

journal homepage: www.elsevier.com/locate/habitatint

Mapping the margins: A systematic scoping review of the impact of digital mapping on public participation in informal settlements

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ARTICLE INFO

Keywords:
Informal settlement
Digital mapping
GIS
Participation
Urban planning
Global South

ABSTRACT

Informal areas in the Global South are still relatively under-researched. This is partly due to the difficulties associated with accessing these areas, especially when it comes to more complex research topics such as understanding the daily lives of residents and other phenomena that are difficult to measure from the outside or purely through data. In planning, access to informal areas is relevant not only for research, but also for civic participation. The latter has become mainstream in recent years, leading to a growing body of literature on participatory planning. Participation typically involves some form of data collection and, since much data is spatial, mapping, most of which is now done digitally. However, little is known about the interface between digital mapping (in the sense of geodata acquisition involved in wider participatory mapping activities) and participation in informal contexts. This review explores that interface. The collected corpus of articles was assembled according to a rigorous protocol and analyzed using a thematic analysis approach. The results show that digital mapping has so far resulted in relatively little additional direct participation by affected residents. However, the results show a number of side effects that have a positive impact on the involvement of informal area residents in the political planning process. We also note that the relevant studies often focus on a few select countries per continent, which may have an impact on the transferability of the results published in the literature. We hope that this scoping review will be useful to both planning researchers and practitioners.

1. Introduction

The proportion of people living in informal conditions has risen in recent decades and in the wake of a generally increasing degree of urbanization around the world. The rapid development of cities is often accompanied by a lack of affordable housing and resulting inadequate living conditions. This situation can encourage the emergence of informality (Sandoval & Sarmiento, 2020), with now more than one billion people living in informal settlements (United Nations Statistics Division, 2022, p. 48), a number that is expected to increase to more than three billion people by 2050 (United Nations Habitat, 2022, p. 79). Informal settlements continually suffer from a lack of public and political visibility (Kamalipour & Dovey, 2019), which means that their residents are not always able to claim their rights as citizens. Part of this invisibility is a lack of data on these areas, making it difficult to conduct appropriate research on living conditions therein. This makes it easy for governments to deny recognition to the communities in question, thus avoiding the addressing of unpopular issues. The outlined context leads to the geographical, economic, social, and political isolation of informal settlements and prevents the adequate participation of their inhabitants in urban opportunities and decision-making processes (United Nations Human Settlements Programme, 2015).

Some recent strategies to better engage marginalized groups of people from informal settlements rely on technological means to put new participation formats into practice. In doing so, solutions are sought to overcome some of the limitations of traditional participation models (e.g., Gordon et al., 2011; Hanzl, 2007). In this context, digital mapping of informality has recently been discussed as a tool both to collect data for scientific purposes (for a recent review, see Abascal et al., 2022) but also to empower neglected populations and better integrate excluded areas into the urban context. In this sense, Luque-Ayala and Neves Maia (2019) point to the use of digital mapping as, at its core, political technique. By exploring the link between digital visibility and urban inclusion, Neves Maia (2018) concludes that the former does not automatically imply the latter. Nevertheless, improved digital visibility, when paired with other strategies for managing other types of (in)

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https://doi.org/10.1016/j.habitatint.2024.103040
Received 26 August 2023; Received in revised form 8 February 2024; Accepted 14 February 2024
Available online 4 April 2024

visibility, has the potential to promote political change. While they appear promising, we still need a better understanding of the efficacy of digital tools and strategies in the field of spatial planning. This includes a better understanding of how we can use such tools and strategies in meaningful ways to address some of the challenging issues facing cities, and informal settlements in particular.

Our research presented subsequently synthesizes and discusses digital mapping processes in informal settlements including connections to participation, planning, and decision-making. The research question we explore is: How does the digital mapping of informal settlements affect public participation in planning for both the mapped areas and their residents? The goal of our study is to explore what we know about the potential impacts and benefits of digital mapping for informal settlements in planning practice and research. Furthermore, we aim to examine how digital maps can be used to empower marginalized communities. In addition, we aim to summarize and understand the current state of digital mapping approaches for informal settlements. Therefore, we analyze both different approaches to digital mapping, as well as the characteristics of the mapping tools and data used. To achieve these objectives, we have conducted a systematic literature review consisting of the following steps: problem definition, formulation of a search strategy, identification of literature selection criteria, and formulation of an analysis strategy. Through this approach, we provide a comprehensive analysis of the topic integrating findings from a broad range of topical fields.

The remainder of this paper begins with a brief discussion of the main terms and concepts employed throughout this work in Section 2. Based on this, Section 3 provides a brief literature review introducing related overviews and review papers in the proximate thematic context of our research question outlined above. After presenting the literature review strategy in Section 4, we describe and discuss the obtained results in Section 5 and close with a set of conclusions in Section 6. Please note that the following review focuses on a specific subset of the extensive research on participatory mapping conducted in recent decades. For more general overviews and review articles on participatory mapping beyond digital approaches and informal contexts, we refer the interested reader to relevant recent articles (e.g., Denwood et al., 2022; Hasanzadeh, 2022; Álvarez Larrain & McCall, 2019).

2. Terms and concepts

In this article, we use three key terms that are either contested or ambiguous. These terms therefore require a brief introduction so that the reader knows not only what they mean but, equally important, how we use them in our work. These terms are *digital mapping*, *public participation*, and *informal settlement*, and they are briefly discussed in the following subsections.

2.1. Digital mapping

In this study, we use the concept of digital mapping as elaborated by Clarke (1995), who describes digital mapping as a method by which a group of geographical data is organized and structured into a virtual image. In addition to this technical perspective, we consider the societal dimension of mapping and its role in communication, which have been discussed by MacEachren and Kraak (1997) and MacEachren and Fraser Taylor (1994). These authors argue that digital maps can be divided into two categories. The first describes mapping as a tool used for analysis, to solve problems, and support decision-making processes. In our study, this category includes also locative techniques of social-empirical research, such as geolocated surveys or interviews, as there is an increasing conflation of mapping, locative technologies, and traditional social-empirical data collection (Bluemke et al., 2017). The second category of mapping refers to maps as a tool for communication, an aspect the core fundamentals of which are still subject to research (Mocnik, 2023). Since all the aspects elaborated above play a big role in the context of spatial planning, we refer here to digital mapping not only in a purely technical sense, but in the sense of this holistic understanding.

Digital mapping in the given context of informality is also subject to limitations. One of those is a lack of generally applicable best practices for mapping informality itself and other aspects under the condition of informality (Thomson et al., 2020). In addition, Rzeszewski and Kotus (2019) note that the use of technology in this area is hindered by a potential lack of technological knowledge in target communities, among other barriers (see Section 3). Thus, the application of digital mapping in the informality domain can lead to biases in data collection, organization, analysis, and results derivation. This raises questions about the expected outcomes of such practices, including whether they produce greater social engagement, reinforce inequalities in recognition of rights in informal settlements, or have no effect at all.

2.2. Public participation

Our research borrows the concept of public participation from the classic and widely used 'ladder of participation' proposed by Arnstein (1969). According to this concept, participation can be divided into eight levels. The first two stages, manipulation and therapy, refer to non-participation and will therefore be neglected in the remainder of this article. The next three stages, information, consultation, and pacification, are referred to as *minimal empowerment* because they allow participants to express their views but do not guarantee that these will be taken into account, and decision-making power remains with a select few. The following category, referred to as *levels of citizen power*, begins with partnership, which allows citizens to negotiate on an equal footing with those in power. This is followed by delegation of power and citizen control, where citizens who were not previously in power now have majority or complete control over decision making. Furthermore, Fung (2006) argues that the distinction between different forms of direct participation can be made based on three dimensions: (1) the people who participate, (2) the methods used to share information and make decisions, and (3) the link between discussions and public policy. Thus, it can be said that improving public participation in planning practice can involve promoting community awareness, improving collaboration among informal settlement residents, policy makers, and other stakeholders, and equipping individuals with the means and authority to participate in discussions and decision making. Thus, we are interested in analyzing the link between digital mapping and the empowerment of informal communities along two dimensions. On the one hand, we consider participation as a process comprising elements such as community understanding of concepts, variables, and possible outcomes of actions and decisions, as well as social impacts. On the other hand, we examine the tools and their technical aspects, such as accessibility, interface, replicability, and the actors involved in their development.

2.3. Informal settlements

We use the definition of informal settlements proposed by Kamalipour and Dovey (2019), who establish these settlements as urban areas that have grown in absence of official control of urban design, planning, and construction. Access to basic services is limited and residents often have to cope with inadequate facilities such as poorly maintained public toilets, inadequate waste disposal, unprotected sewage systems, and irregular street lighting (Wallerstein & Duran, 2006). Furthermore, according to this definition, informal settlements usually comprise residential areas that lack basic infrastructure such as electricity, water, and sanitation services (Kombe, 2005). This definition is sufficiently unambiguous from a planning perspective allowing us to pinpoint lacking planning efforts in affected areas, but broad enough to encompass different types of informal settlements such as African shantytowns, South American favelas, and others. The latter is important because our study takes a global perspective.

3. State of the art

Digital mapping in the context of participation is still more widespread in the Global North, both in practice and in academia (Brown, 2017; Brown & Fagerholm, 2015). However, there is also a shift towards the use of digital approaches in the context of informal settlements and more generally in the Global South (Nicolosi et al., 2020; Tulloch, 2007), although the digital technology required is often funded by external actors from developed countries (Brown, 2017) and the actual conduct of such mapping is subject to logistical challenges like the availability of internet infrastructure or even of electricity (Weyer et al., 2019). One reason for the switch to digital mapping is probably the needs of stakeholders. Kuffer et al. (2021) conducted an international, large-scale survey among private, governmental, non-profit, and academic stakeholders regarding their needs in mapping informal areas. The results show that more than 50% of respondents have a need for (and complain about the lack of) timely data. Furthermore, the majority of stakeholders have a need for data at the neighborhood level, but only 5–30% of them (depending on the type of stakeholder) use participatory mapping, which seems to be well suited for collecting such information. Thus, there is still much potential for the integration of digital technologies and participatory mapping in informal contexts.

A recurring theme in the literature is the technologies used for digital mapping. Mapping informal areas can generally be categorized into three types of underlying technologies (Aditya et al., 2020; Thomson et al., 2020): satellite imagery, participatory mapping and crowdsourcing, and geo-referenced household surveys. Research has shown that a combination of sketch mapping (i.e. externalizing an internal geographic model of the world; see Wang & Schwering, 2015) with satellite imagery as a base map (e.g., using an appropriately sized tablet computer) is both comparatively simple and efficient when it comes to making residents feel empowered and involved (Aditya, 2010; Akbar et al., 2021; DeGraff & Ramlal, 2015; Eilola et al., 2019). Participants in corresponding workshop-based mapping activities have reported that they find satellite images easier to interpret and therefore often prefer them to vector-based maps (DeGraff & Ramlal, 2015), although the geometric accuracy of derived geometries (at least when digitizing physical features) can be inconsistent across multiple human interpreters (Brown, Weber, & de Bie, 2015; Leonita et al., 2018). In addition, sketching provides a flexible component that allows participants to express their opinions in a structured way. However, one problem with this approach is the limited diversity of the audience, as the face-to-face approach only appeals to certain segments of the target communities. For the context of the Global North, Jankowski et al. (2019) have shown that web-based mapping counterparts can effectively address this problem, although it remains questionable whether such an approach is feasible under informal conditions due to the potential lack of sufficient infrastructure in many such locations. However, initial results on internet-based mapping, including in the Global South, show that participants find it effective, efficient, and easy to learn (Aditya et al., 2020). But it was also shown that broad participation of inhabitants of informal areas is still a challenge. Rzeszewski and Kotus (2019) have conducted a study using web-based participatory mapping in post-socialist contexts, but assert that their findings are to some extent transferable to the Global South. They have concluded that the demographics of such approaches tend to be skewed towards younger and more educated participants (Brabham, 2009; Czepkiewicz et al., 2016) and that while many participants are familiar with browsing maps, they lack familiarity with creating spatial objects such as points, lines, and polygons (Brown & Pullar, 2012; Pocewicz et al., 2012). The latter will probably also be the case in informal areas of the Global South. In contrast to non-digital participatory mapping, the additional use of smartphones, cameras, and other digital devices enables the enrichment of maps with geo-referenced videos, photos, and other media types, even though these devices are still emerging technologies in informal contexts (Brown & Kyttä, 2018). However, such technologies offer the opportunity to convey stories, legends, and other important information from informal contexts, as maps alone are limited in their ability to unlock vernacular knowledge (Corbett & Keller, 2005). "[R]esults show that empowerment and empowerment capacity are more closely related to the multimedia components […], rather than the geographic/mapping element of the technologies" (Corbett & Keller, 2005, p. 38). It therefore seems to be a mixture of technologies that is advantageous in the digital mapping of informal areas.

A number of positive impacts of digital mapping of informal areas have been reported at both individual and community level. A number of studies have shown that participants gained both leadership and technological skills through digital mapping (Corbett & Keller, 2005). Nevertheless, some faced envy from others and some even lost status because they were considered 'too ambitious' (Corbett & Keller, 2005). However, as computers are associated with certain lifestyles and having the appropriate skills improves career opportunities, a large number of participants in digital mapping campaigns also tended to benefit personally (Corbett & Keller, 2005). Digital mapping also legitimizes the knowledge of residents of informal areas (Weyer et al., 2019) and puts informality at the center of analysis, leading to increased attention (Banks et al., 2020). It also enables communities to learn about themselves, their places, and their history (Brown, Raymond, & Corcoran, 2015). In terms of gender, a study by Akbar et al. (2021) has shown that female participants show great interest in digital mapping, but do not always feel confident to participate. Similarly, Corbett and Keller (2005) show that female participants were empowered by digital mapping activities (e.g., in terms of technological skills), but that some of them faced tensions at home because their husbands accused them of sidelining their domestic chores. These dualisms show the importance of considering cultural contexts such as established patriarchal value systems when designing digital participatory mapping campaigns. Unfortunately, in the vast majority of cases, there is no effective adaptation of participation and mapping software to specific context conditions, leaving our knowledge of how to better adapt software to them limited (Brown & Kyttä, 2018; Kuffer et al., 2016; Olson et al., 2016). Correspondingly, researchers have recently called for a comprehensive, unified framework for mapping informal areas to better capture the complexity and dynamics of deprivation in low- and middle-income countries (Abascal et al., 2022). Akbar et al. (2021) also show that the maps resulting from digital participatory mapping helped residents to structure their opinions, which they might otherwise have struggled to express. It may also be that digital mapping provides more detailed maps than analog counterparts (Thom et al., 2016). In addition, the use of digital technology (which is not typically common in informal settlements) can create a sense of pride that can contribute to a long-term interest in participation (Corbett & Keller, 2005; Vergara-Perucich & Arias-Loyola, 2021). The latter can be supported by an improved understanding of the participants' right to be heard by policy makers, as noted by Vergara-Perucich and Arias-Loyola (2021). The same authors also show that digital mapping has led informal area residents to develop a stronger notion of the importance they attach to the different parts of the informal areas they inhabit. From a procedural point of view, digital mapping reduces the effort required to post-process data (Olson et al., 2016) and facilitates the involvement of multiple stakeholders in participatory processes, which may increase the legitimacy of data for policy making (Elwood, 2006).

Digital participatory mapping of informal areas can also have negative ramifications and consequences for both the communities concerned and the planning processes at stake. For example, it is possible that such mapping activities reveal locations of sensitive places and inadvertently expose them to external stakeholders (Rambaldi et al., 2006) – a problem that can be exacerbated by digital mapping due to the easier shareability of digital artifacts (Taylor & Broeders, 2015). Power imbalances are also often still at play, at different levels and stages of the mapping process. During mapping, these may be caused by socially privileged individuals exercising their authority in the community, due

to imbalances in the distribution of technological skills in a community, or because the act of mapping may lead to disputes over boundaries or provoke land-grabbing conflicts (Akbar et al., 2021). Some residents may also be in opposition because they do not want outsiders to interfere but want to improve their informal areas themselves (Bautès et al., 2013). At higher political levels, including the approval stages of digital mapping activities, there may be powerful opponents who try to block the implementation of a project, for example, if they are involved in land grabbing or other illegal activities that might be compromised by the mapping (Ndemo, 2020). Digital mapping in informal areas also confronts facilitators with the need to train residents, as they may not be familiar with the relevant technologies, and to familiarize them with a representation of the world that follows a digital logic that may differ from their own (Falco & Kleinhans, 2018). The latter means that facilitators need to develop a critical view of their own cultural assumptions in order to pay attention to possible epistemological differences (Scassa et al., 2015). Epistemological differences can also lead to epistemic injustice in digital mapping. For example, if local vernacular knowledge from informal settings is implicitly or explicitly disregarded or invalidated, participants may not feel taken seriously (Fricker, 2007; Weyer et al., 2019). As many ethics committees may also not be familiar with the specific requirements of digital mapping in informal contexts, it is paramount to communicate carefully with the target communities and in particular to avoid technical jargon, as the target group of participants may not be familiar with it (Weyer et al., 2019).

Advantages and disadvantages of digital participatory mapping and its potential impact on participation have thus been identified. Both should be considered with caution, as after decades of research on participatory mapping, the number of conclusive evaluations based on solid, tangible evidence of its social impact is still relatively limited (Brown & Kyttä, 2018). Regarding the impact of digital mapping on empowerment, many participants in the respective activities have reported that they felt, at least subjectively, that they had an influence on policy-making (Akbar et al., 2021). Whether this is actually the case is another question. For example, the legal basis for participatory mapping in Indonesia is unclear, so it is not certain to what extent the resulting data is (or even can be) taken into account in formal spatial planning (Akbar et al., 2021). Mixed experiences were reported in a Chilean case study. There are cases where authorities have considered participatory mapped information from informal areas at different policy levels (Casgrain & Janoschka, 2013; Del Romero, 2018; Serrano, 2009). However, Vergara-Perucich and Arias-Loyola (2021) also report that this is not generally the case and that Chilean government officials often view bottom-up initiatives with suspicion. Such conservative attitudes can be an important demotivating factor for potential participants. Brown and Kyttä (2018) also report that, like many government officials, potential participants themselves view digital mapping activities with skepticism, especially when they are initiated and carried out by outsiders. This is partly due to the negative impacts described above, but also to the fact that digital information is much harder to control as it can be widely disseminated and analyzed in more complex ways (Taylor & Broeders, 2015). Some communities in the Global South may also have been subjected to dictatorial conditions over a long period of time. These people are naturally reluctant when external digital mapping actors appear in vehicles with modern equipment, as they may deem them elitist and authoritative (Weyer et al., 2019). Such concerns are also fueled by private actors such as large technology companies that promote participatory mapping activities. Luque-Ayala and Neves Maia (2019) discuss a case of Google providing favela mapping in Brazil and conclude that the company is interfering in a way that is both state-like (for which the company has no mandate) and (out of commercial interest) prioritizes the economic dimensions of the favelas. The latter involves suppressing the actual concerns of residents, including their mapping, possibly leading to a technological form of neocolonialism and a perpetuation of pre-existing inequalities in the affected areas (Leszczynski, 2016; Rambaldi et al., 2006; Ramirez-Gomez et al., 2013; Wynne-Jones et al., 2015). These and other structural issues related to digital mapping of informal areas are closely linked to managing expectations and building trust (Brown & Kyttä, 2018) (although there are also counterexamples where residents proactively approach academics regarding facilitating digital participatory mapping, see Vergara-Perucich & Arias-Loyola, 2021), and they pose significant challenges to the realization of actual resident participation. Participation therefore often remains rather shallow even with digital mapping (Brown & Kyttä, 2018). The following systematic scoping review aims to add to the works outlined by synthesizing the available evidence on the intersection of participation, digital mapping, and informality.

4. Methodology

In the present research, a systematic literature review (SLR) was conducted as the main method. Systematic literature review is a widely accepted and standardized method to identify, critically appraise, and synthesize relevant research studies on a given topic or research question (Kitchenham, 2004). With this approach, a comprehensive and exhaustive literature search is conducted according to clear criteria, followed by a rigorous assessment of studies based on predefined inclusion criteria. The SLR process offers several advantages, such as the ability to identify and analyze the bulk of all relevant studies related to a research question, minimize biases such as those due to potential prejudice, and ensure transparency in the selection and assessment of studies (O'Brien & Mc Guckin, 2016). Therefore, it can be assumed that the SLR method used in this study, the individual steps of which are described in the following sections, provides a reliable and robust synthesis of the literature on the present research question.

4.1. Problem definition

The purpose of this study is to examine how digital mapping of informal settlements affects participation in the planning sense and in relation to the residents of the mapped areas. The aim of this study is to identify and document the results of experiences and approaches related to digital mapping in informal settlements in participatory contexts in emerging economies and the Global South.

4.2. Search strategy

For data collection, we conducted an extensive search of the well-known and widely used databases Scopus and Web of Science. These databases cover a wide range of disciplines, including those relevant to the scope of our work. The papers we collected include works in the fields of planning and geography, but cannot be pinned down to a definitive group of disciplines or fields because the topic is inherently interdisciplinary. For this reason, both Scopus and Web of Science are considered well suited to identifying relevant papers because of their wide coverage. To achieve the research objectives of our systematic literature review, we define search strings that include the three keywords outlined in Section 2: digital mapping, informal settlement, and participation. These keywords are identified as essential categories that are required to feature and be tied together in the literature relevant to this study. To ensure a comprehensive search, we assigned alternative terms to each keyword that are commonly used in the literature (though they are not always exactly synonymous). The keywords and alternative terms are presented in Table 1.

We developed search strings for both databases by combining the mentioned keywords and their synonyms. The way we combine the keywords follows a bag-of-keywords logic. Each identified manuscript must satisfy all three categories in order to enter our initial shortlist of potentially relevant papers. The respective search strings are shown in Table 2. To perform a comprehensive search, we used the "ALL" option in both databases, which allows searching for the defined terms in several fields, including subject, title, abstract, and keywords. In

Table 1
Research keywords and synonymous terms.

Keyword	Alternative terms
Digital mapping	Web mapping, GIS, geographic information system
Informal settlement	Informal area, informal neighborhood, informal territory, informal space, deprived settlement, deprived area, deprived neighborhood, deprive territory, deprived space, illegal settlement, illegal area, illegal neighborhood, illegal territory, illegal space, informality, slum, favela, shantytown
Participation	Engagement, inclusion, collaboration, involvement

Table 2
Search strings used for database querying.

Database	Search string
Scopus	ALL("digital map*" OR "web map*" OR "gis" OR "GIS" OR "geographic* information* system*") AND ALL("informal settlement*" OR "informal area*" OR "informal neighborhood*" OR "informal territor*" OR "informal space*" OR "deprived settlement*" OR "deprived area*" OR "deprived neighborhood*" OR "deprived territor*" OR "deprived space*" OR "illegal settlement*" OR "illegal area*" OR "illegal neighborhood*" OR "illegal territor*" OR "illegal space*" OR "informality" OR "slum*" OR "favela*" OR "shantytown*") AND ALL("participat*" OR "engagement" OR "inclusion" OR "collaboration" OR "involvement") AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp"))
Web of Science	((ALL=("digital map*" OR "web map*" OR "gis" OR "GIS" OR "geographic* information* system*")) AND ALL=("informal settlement*" OR "informal area*" OR "informal neighborhood*" OR "informal territor*" OR "informal space*" OR "deprived settlement*" OR "deprived area*" OR "deprived neighborhood*" OR "deprived territor*" OR "deprived space*" OR "illegal settlement*" OR "illegal area*" OR "illegal neighborhood*" OR "illegal territor*" OR "illegal space*" OR "informality" OR "slum*" OR "favela*" OR "shantytown*")) AND ALL=("participat*" OR "engagement" OR "inclusion" OR "collaboration" OR "involvement")

Table 3
Pre-established statements used for abstract screening.

Statement 1	The article should specifically address informal settlements in emerging economies and the Global South as the object of study.
Statement 2	The paper should address the concepts according to the established definitions from Section 2.
Statement 3	The paper should address the relationship between digital mapping and social participation in the context of planning.
Statement 4	The paper should not focus solely on the technological tool, but rather on the procedural aspects of digital mapping or the resultant planning practices.

addition, we restricted the search to journal articles and conference papers, as these are usually peer-reviewed. This last step was achieved by selecting the relevant document types in each database. The search was not limited to a specific time period, as this is not relevant to our research objectives. On the contrary, analyzing articles from different years can provide a more comprehensive understanding of how the relationship between the identified keyword groups has evolved over time. We also limited the search to documents published in English since the target scope here is an international one. We further allowed for different inflections of the keywords through using asterisks acting as wildcards. Both databases were last queried on 29 December 2023.

Our approach is not without limitations. One limitation is that conference papers and book chapters are not exhaustively included in the two databases employed. However, we assume that most papers relevant to the given context will be published in peer-reviewed journals, as this is the main form of publication for original research, at least in the fields of planning and geography. Future studies may look more closely at conference papers and book chapters. Another limitation is that our approach does not cover non-academic manuscripts such as white papers and practitioner reports. Thus, our study focuses on peer-reviewed academic literature and may reflect practical planning to a lesser extent, unless the latter is used as a case study in the context of an academic article. Our focus on English-language documents is also a restriction that we make for pragmatic reasons. It would, of course, be very interesting to also learn about possible differences in relation to our topic between English-language and other-language works. Future research may add this perspective.

4.3. Abstract screening

The resulting references from our database queries, including authors, year of publication, title, and abstract, were exported to an Excel spreadsheet and filtered for duplicates, resulting in a total of 2141 unique articles. The abstract of each article was then reviewed to identify manuscripts that deal with cases in emerging economies and the Global South and that are relevant to the research objectives. We focus on this geographic area, as the vast majority of informal settlements are located in this part of the world[1]. The first step was to assess the congruence of each article with four pre-specified statements, which are presented in Table 3. A ranking system was used, assigning a score between 1 and 3 depending on the degree of agreement. A score of 1 indicates no agreement, 2 indicates partial agreement, and 3 indicates complete agreement with each statement. Next, the papers that received a score of 2 or 3 for all four statements were selected, resulting in a total of 150 articles. In a second step, the articles that had received a score of 2 for one or more statements were reexamined. In some doubtful cases, a more detailed analysis of the article was already performed at this step beyond the abstract. From these, a total of 51 articles were selected, but seven of these were either not available for download or were not in English despite our defined query and were therefore excluded. The final list of papers thus comprises 44 articles.

4.4. Analysis strategy

The identified literature was fully read and analyzed using a thematic analysis approach. The main goal of the analysis is to identify recurring patterns and themes (and, in addition, selected relevant individual non-recurring themes) in the literature to answer the research question. For the analysis strategy, we identified four themes (see Table 4), which were recorded in an Excel spreadsheet. To facilitate categorization of the data, a color-coding system was developed to highlight specific themes as we read the articles (the color codes are labeled I–IV in Table 4). The Excel spreadsheet was used to provide a concise summary of key discoveries to facilitate linkage of article content and visualization of extracted data for synthesis.

The four themes listed cover different aspects of our research. Theme I provides a descriptive characterization of the type of research that has

[1] An alternative term for this part of the world is Majority World. Other alternative terms include Developing World and Third World, although these are no longer commonly used in the scholarly literature. See Alam (2008) and Mitlin and Satterthwaite (2013) for related discussions.

Table 4
Themes and their associated codes.

Code	Content
I	Case study location
	Employed mapping tool
	Type of data used or generated
	Replicability
II	Digital mapping approach
III	Impact of digital mapping on participation
IV	Additional, minor findings

been conducted in the areas relevant to this study. This theme comprises four sub-themes. We recorded the locations of the case studies to gain an idea of the geographic focus of the digital mapping and participation research. This allows us to identify potential blind spots, but also helps us to better understand how representative the results obtained for other themes are in terms of their geographic distribution. Sub-themes two and three deal with tools and data types, allowing a summary of the more technical aspects of the research topic. The fourth sub-theme, replicability, is of more secondary importance here, but will help us assess how transferable the approaches are.

Themes II and III are the main subjects that relate directly to our research question. Theme II goes beyond the aspects of tools covered by theme I and aims to identify more comprehensive mapping strategies. This includes the tools used, but links them to broader approaches at different stages of the mapping process. For example, it may be important to understand how different tools are used in combination or how local residents are involved in the mapping process to gather local knowledge. Topic III focuses on those text segments that address specific linkages between digital mapping and participation as part of planning processes. This includes, among other things, how the mapping process itself or its results are translated into participatory approaches, and in what ways true participation actually occurs in the sense that the results are seriously taken into account. Finally, theme IV is a residual category that allows us to take note of anything noteworthy that does not fall into the other categories but may be important to the research context at hand. These additional and possibly singular findings may be of interest in identifying follow-up research topics. Also, the additional information identified in this way could be useful for further contextualizing the other findings.

5. Results and discussion

In the following subsections, we present our results of the review. Section 5.1 first briefly characterizes the published research conducted on the topic. This characterization is presented broken down by the sub-themes of Code I from Table 4. After this descriptive section, we address our research question in Sections 5.2 and 5.3, thus addressing Codes II and III. Finally, Section 5.4 summarizes additional relevant findings that do not respond directly to the research question but may be relevant to further research in terms of hypothesis development.

5.1. Descriptive characterization

The descriptive characterization below summarizes the case study sites, mapping tools used, types of data used or generated, and comments on replicability.

5.1.1. Case study locations

Most of the literature reviewed includes case studies conducted in specific, clearly identifiable geographic locations. Some articles even cover more than one case study. It should be noted, however, that four of the articles analyzed deviate from this approach and do not present a particular locatable case study at all. In terms of the geographic locations of the case studies, the majority of the identified literature focuses on locations in developing regions, as shown in Fig. 1. The majority of the research focuses on studying sites on the African continent. Twenty-seven articles examine cases in Kenya, South Africa, Nigeria, Rwanda, Tanzania, Egypt, Sierra Leone, Liberia, Mozambique, Ethiopia, Benin, Chad, and Zimbabwe. The second most studied continent is Asia, with twelve articles examining cases in India, Indonesia, Bangladesh, Pakistan, Mongolia, Papua New Guinea, and Nepal. Next, there are nine articles examining cases in South American countries, including Brazil, Peru, Chile, Venezuela, and Argentina. Finally, only one paper examines a case in Mexico and thus in Central America. Please note that some articles examine more than one case study. What this overview shows is a strong concentration on a few case study countries. For example, the findings from Africa are mainly concentrated in South Africa and Kenya. The latter includes Kibera, a deprived area in Nairobi that has become a very popular study site over the years. From this we can conclude that while some cases are well studied, there are still large white spots on the map, leaving much of the Global South in the unknown. The latter is a problem because the corresponding research often includes policy advice components that might vary in other national contexts.

5.1.2. Employed mapping tools

Geographic Information Systems (GISs) represent the most commonly used tool for digital mapping of informal settlements in our corpus. The literature reviewed highlights the potential of this type of tool, which, according to many authors, is characterized by geometric accuracy, versatility, and efficacy, to provide insights into the spatial patterns and characteristics of informal settlements. Among the various types of GIS applications, Participatory GIS (PGIS) in particular has been the focus of several studies. PGIS allows for consideration of the expertise and knowledge of local communities in shaping their own neighborhood development. Web-based platforms have also been used in several cases, with OpenStreetMap (OSM) being the most popular and widely used mapping platform. OSM provides free access to geographic features such as streets, buildings, and other elements of the physical and built environment. In addition to OSM, other platforms such as GISColab (Moura et al., 2021) and the Brazilian Geodesign Platform (Moura & Freitas, 2021) were used as well. In addition, in some cases, unmanned aerial vehicles (UAVs) were used in the mapping process. Finally, the inclusion of GPS receivers as standalone systems is mentioned in a small number of cases.

5.1.3. Type of data used or generated

Based on the literature reviewed, we identified three main categories of data: imagery, vector data, and tabular attribute data. The imagery used in the case studies is of a variety of types, including drone imagery, traditional forms of remote sensing data, and photographs. We note that unmanned aerial vehicle (UAV) imagery is used extensively in digital mapping scenarios in informal settlements. We hypothesize that UAVs are preferred for capturing imagery data because they can be used flexibly and at comparably low cost, can cover large areas from a given location, and provide high-resolution imagery from different angles and altitudes, providing a comprehensive view of the area being mapped. In addition, UAVs can capture imagery in near real time, which allows for rapid updating of map data. The latter is particularly useful in dynamic environments. A second category of data used for digital mapping is vector data. This data usually consists of points or other features that are mapped either with an image recognition tool or by manually drawing vector geometries with GIS software. A commonly used type of tool for creating vector data are editors in the context of the aforementioned OSM, which often also allow importing data from other sources. A third category of data used in digital mapping is tabular attribute data, which is used to qualify imagery and vector data. Tabular attribute data include various types of information such as census data, field survey questionnaires, sample interviews, and information from researchers in the field. These data sources provide valuable insight and context for the mapped sites and allow for a more comprehensive understanding of mapped areas.

Our analysis of digital mapping cases shows that multiple types of data have been used in complementary ways. We frequently encountered examples in the articles where obstacles to data collection were overcome through the use of volunteered geographic information (VGI), that is, geographic information contributed by lay volunteers, and other types of local community participation. Therefore, and in the light of the complexity of many informal areas, it is essential to include the affected population in the data collection process in order to accurately represent the regions studied. By including the perspectives and experiences of those who live in the mapped areas, the maps produced become more representative of the reality on the ground. Overall, using a combination of data types and working with local populations can result in comprehensive and accurate digital maps of informal areas.

5.1.4. Replicability

For the most part, the methods and techniques used in the literature discussed can be applied to other cases and contexts. However, it should be kept in mind that some of the approaches are highly contingent on contextual characteristics, such as particular forms of governance or the specific characteristics of a particular project. In addition, a negligible proportion of the cases studied were classified as non-replicable because they are too case-specific. The results suggest that digital mapping approaches for informal settlements are generally adaptable to different settings, indicating that they can be replicated in a variety of contexts, at least at a more technical level though not always at a policy and procedures level. These findings have significant implications for the scalability, sustainability, and potential of digital mapping of informal settlements to address the challenges faced by these areas and their inhabitants around the world.

5.2. Digital mapping approaches

In a large proportion of the cases studied, VGI was an essential component of the approach to mapping informal settlements. VGI refers to the use of digital tools to collect and share volunteered geographic data, mostly provided by private individuals (Goodchild, 2007). In this way, the experiences and viewpoints of a variety of people can be incorporated without the need for official legitimization or permission to collect data. The latter is often complicated, especially in the informal settlements in the Global South discussed here, and often entails lengthy negotiations. Furthermore, in the given context, VGI may be more adaptable, spatially diverse, and temporally extensive than traditional methods (Ferster et al., 2018). In most of the relevant case studies, OSM was used as a VGI tool for recording and cataloging geographic information, with the exception of one case in Venezuela where Google My Maps was used to create vectors and boundaries of informal areas (Falco et al., 2019). During our review, we also found that a recurrently cited key advantage of VGI is that it is quick, comparatively straightforward, and inexpensive to generate data. This makes VGI an amenable approach, particularly for crisis situations where rapid response is required and data must be generated quickly to assess the situation on the ground. VGI has the potential to provide more accurate, timely, and comprehensive data than traditional methods because it draws on input from a diverse group of individuals who can provide a range of viewpoints and experiences. This is a major advantage, particularly in the complex informal settings of slums, shantytowns, and favelas, the inner structuring of which is often hard to grasp for outsiders. In addition, VGI can engage otherwise underrepresented communities in mapping, as they can bring their local knowledge and experience to the creation of

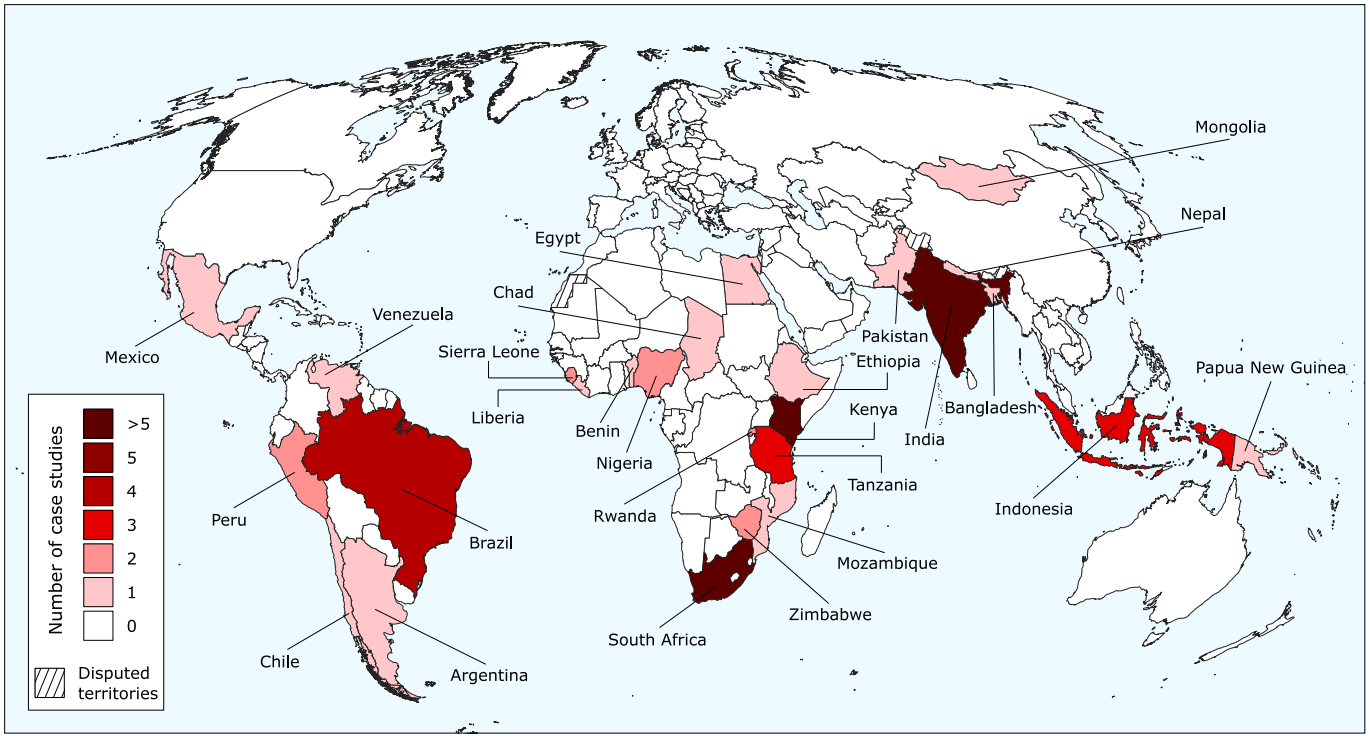

Fig. 1. Overview map showing the number of case studies per country as identified in the review. Disputed borders are shown with dashed lines. Please note that Hawaii and some other Pacific islands are outside the map extent due to the global projection used, as we want to focus on those parts of the map that are relevant for this article. The projection used is Mollweide (EPSG: 54009; see Lapaine, 2011), which is an equal-area but not an equidistant projection. For this reason, no scale bar is given. The underlying administrative boundaries are published under an Open Government License and reflect the boundaries of the UN World Food Programme. Some larger disputed areas are marked, but disputed borders are not shown for reasons of readability. This does not represent any political partiality on the part of the authors, who remain explicitly neutral. The underlying boundary data are provided by opendatasoft.[2]

[2] https://public.opendatasoft.com/explore/dataset/world-administrative-boundaries/export/, last accessed on 28 December 2023.

geographic data. This was the particular case in Bagelen (Indonesia) by Purwitaningsih et al. (2022), for example, where printed maps were validated through interviews with residents and cross-checked with them to confirm the locations of floods. In addition, VGI can promote transparency because the generated data are openly accessible. Some of the world regions considered here are subject to problematic political complexities. VGI can be used in these cases, for example, to hold decision makers accountable for their actions, showing that the use of VGI in mapping informal settlements may have positive effects beyond the actual mapping campaign. This can be particularly important in situations where access to official data is limited or where official data is incomplete or unreliable (Jochem & Tatem, 2021). Because of the above reasons, VGI is used in a variety of applications, including emergency response, community development, and for scientific research.

We also identified the frequent use of questionnaires to collect and validate data. The use of questionnaires can play a critical role in assessing vulnerable communities because they provide a structured approach to collecting sensitive data related to that very vulnerability. This includes demographic information, socioeconomic status, health issues, and access to services. In some cases, questionnaires have been conducted using spatial sampling methods such as a mapping approach in Kenya (Bakibinga et al., 2019). On the one hand, these types of questionnaires do offer limited geographic accuracy. On the other hand, the willingness to share relevant data is considerably greater than in the case of permanently publicly accessible datasets. The use of questionnaires by researchers is also sometimes an important tool for governments (at least for those with willingness to cooperate and positive intentions). For most of the regions designated as informal settlements, insufficient official data were available, making it difficult to understand the situation on the ground. Ultimately, the involvement of local, affected communities has proven to be a key element in the majority of digital mappings studied. This engagement can take many forms, including data validation, data collection, or general support. These approaches have been effective in implementing mapping and have provided communities with a sense of empowerment, as they were actively engaged in the research process instead of being acted upon. Engaging communities in digital mapping thus not only results in more accurate maps, but also promotes community development, strengthens community ties, and ensures that the resulting maps are aligned with local needs and priorities.

5.3. Impact of digital mapping on participation

Access to spatial information can help empower communities in informal areas and enable better decision making (Pánek & Netek, 2019). However, in our corpus, digital mapping is primarily used for data collection and to a lesser extent for explicit participation. Digital mapping has the potential to map settlements in the absence of census data and can serve as a preliminary means to gather initial information for strategic planning purposes (Ragheb & El-Ashmawy, 2021). However, when it comes to participation, the reviewed papers show that digital mapping is mainly focused on data collection or ensuring the accuracy of planning data. Although these efforts are important in promoting public participation, they comply only with the lower rungs of Arnstein's participation ladder (Arnstein, 1969). In most cases, digital mapping is used only to inform or consult with stakeholders, and there are few cases where it goes beyond these rungs. The Solo Kota Kita project in Indonesia can be cited as an example of how digital mapping and citizen participation can lead to more democratic and inclusive decision-making processes in such urban areas (Heeks & Shekhar, 2019). Similarly, the mapping of Los Arenales in Chile using PGIS has shown that by including the community's history and drawing attention to their agency, they are empowered, increasing their self-esteem and willingness to fight for their rights (Vergara-Perucich & Arias-Loyola, 2021). The participatory mapping program of Dar es Salaam in Tanzania also demonstrates community empowerment by giving the community control and access to spatial information (Gevaert et al., 2018). In addition, processes of collaborative mapping can foster a sense of ownership and engagement among citizens, leading to greater acceptance of policy changes (Loggia & Govender, 2019).

Along with the relatively few cases of strong participation through digital mapping, our corpus also shows that at least digital mapping has the potential to increase participation in informal settlements. Digital mapping tools can promote public participation by allowing people to visualize and understand various features of their own lived realities (Moura & Freitas, 2021). For example, participants can manipulate data, adjust layer transparencies and positions in interactive maps, and add annotation points to actively engage in the process at hand. This interactive experience can lead to a more complete understanding of a given topic and, where appropriate, increase engagement over the longer term. In addition, the creation of maps by communities themselves can empower them to better understand their surroundings, improve their geo-literacy, and literally allow them to practically locate their region on a map (Pánek, 2013). Collaborative mapping may thus enable local community members to express their real needs, concerns, and expectations regarding future upgrading activities (Loggia & Govender, 2019). In addition, using methods that analyze regions block by block can break down complex problems into simpler local issues, providing valuable insights and suggestions for planners and policy makers (Soman et al., 2020). It is expected that the collection of mapped data will provide governments with a better understanding of critical areas to prioritize when developing policies for informal settlements (Falco et al., 2019). In this way, governments can learn to better value locally generated knowledge and thus affected communities. Hence, in the long run, participation could be increased, at least indirectly, through mapping efforts. These efforts are most effective when used as part of a systemic strategy that ensures universal access to information while respecting local knowledge and history.

In summary, the literature reviewed suggests that the most important impact of digital mapping on participation in planning practices is improving information access to spatial information and data collection of informal settlements. In some cases, we also hypothesize that digital mapping will further drive participation and promote effective collaboration among different stakeholders. Overall, digital mapping approaches can enable more thorough and informed planning practices, especially in the diagnosis and analysis phases, which better reflect the actual reality in informal settlements and thus can be responsive to the needs and preferences of affected communities. However, there is still much room for improvement when it comes to equipping local populations with the needed skills on the effective use of these technological resources, ultimately giving them proper decision-making power and control. Thus, it can be stated that, beyond the lower levels of participation (e.g., beyond inclusion in data collection), relatively few direct effects of digital mapping on participatory processes in informal settlements are evident in the literature. However, the indirect effects pointed out above may have positive long-term effects, which allows for an optimistic outlook.

5.4. Additional findings

During our review, we gained additional insights that are not directly related to the research question, but contribute to its broader context. One such type of additional insight is the role of technology in mapping informal settlements. Map representations are strongly influenced by the methods and techniques used in their creation (Martínez et al., 2016). This underscores the importance of critical mapping and the need to be aware of underlying assumptions and potential biases in map production and interpretation. The authors of several studies reviewed report that using only satellite imagery to map informal settlements (which seems a natural choice given the complexity of accessing such areas) may not provide a comprehensive and truthful representation. In order to develop accurate digital maps that depict the intricacies of the local

environment, the incorporation of local knowledge is necessary (Soman et al., 2020; Yeboah et al., 2021). Therefore, working with local communities and conducting comprehensive studies to identify the strengths, challenges, and priorities of affected people is critical to ensure the accuracy of the data produced (Ragheb & El-Ashmawy, 2021; Yeboah et al., 2021).

The use of explicitly participatory geospatial information technologies in informal settlements is considered a promising approach to address the lack of information needed for effective planning (Abbott, 2003). Citizen-based mapping platforms can then indeed be sources that challenge official knowledge and make visible areas excluded from official datasets and maps (Martínez et al., 2016). The use of explicitly participatory mapping approaches also encourages community participation and stakeholder interaction (Gebremedhin et al., 2020). In this regard, collaborative mapping and digital participation offer an alternative strategy for obtaining spatial information that may be more beneficial than traditional approaches used in many developing countries (Pánek & Netek, 2019). It is also worth noting that the use of GIS (i.e., a tool that is not exclusively used to collect and map geographic data but also for their analysis) as a tool to strengthen the capacity and agency of local communities, particularly those that are marginalized or vulnerable, is an emerging practice (Pánek, 2013). From the literature reviewed, it appears that the use of GIS can empower community members to participate in data analysis and decision-making processes in addition to mapping and data collection. This can help in the planning and development of informal settlements and bring participation to higher levels of the ladder of participation.

It is worth noting that in the literature reviewed, concerns are also raised about the quality of information obtained from crowdsourcing and VGI. Some researchers have criticized the use of crowdsourced data, raising concerns that such data may be incomplete, undifferentiated, and prone to error due to the lack of rigorous quality control measures (Thompson, 2016). Even when specialized local mapping teams are involved, the quality of data in digital maps produced by a large number of people and oftentimes in a remote manner may be compromised (Yeboah et al., 2021). Therefore, an alternative solution could be to be more interventionist and require more post-processing efforts through the application of, for example, ISO standards to better ensure the reliability of bottom-up collected geospatial data (Augustinus, 2020). Applying simpler strategies, such as implementing mechanisms like a user authentication system, could also promote data accuracy (Tapia-McClung, 2016). In addition, simple web maps without any further analytical capabilities have been shown to be an effective tool for data visualization and collaborative exploration (Moura et al., 2021; Pánek & Sobotova, 2015), especially for datasets that are too large or too complex to be easily understood using traditional data presentation methods (Mdleleni et al., 2020). Our review of the literature suggests that web maps provide users with higher levels of engagement and interactivity when interacting with large datasets, allowing them to navigate through the information and identify patterns or insights that are not immediately apparent with alternative methods of data presentation. In addition, the ease of use of simple web maps allows a wider range of community members or stakeholders to access and view visualizations (Moura et al., 2021).

It is imperative, however, to consider the differences in access to digital technologies in different social, economic, and geographic contexts. For example, while digital tools can provide rich information, they can still be exclusionary (Martínez et al., 2016). There is a significant gap between marginalized and impoverished individuals and the complex digital mapping technologies used to represent them (Kennedy et al., 2022). In this regard, smartphones are considered a relatively inexpensive and efficient tool for digital mapping that has the potential to facilitate data collection and mapping in areas with limited data availability (Ranabhat & Paudyal, 2019). In addition, smartphones can help promote digital inclusion in underprivileged communities, at least when such devices are already sufficiently available (Moura & Freitas, 2021). However, strategies should be implemented that also take into account the limitations of smartphones, as these are also not always available for economic reasons. To strengthen urban resilience and promote collaboration between communities and local governments, it is essential to implement more participatory strategies that strengthen the collective capacities of the urban poor and produce relevant data (Bandyopadhyay & Nagpal, 2020). In addition, improving the access to spatial information can help residents of informal settlements manage their property more effectively (Pánek & Netek, 2019). It was also shown how cultural and language barriers can hinder mapping and thus also proper participation (Laituri et al., 2023). Some of the additional findings highlighted are closely related to the findings presented in the previous sections. Others contextualize the main findings, and we believe it is important to think of this study not only as taking stock of digital mapping of informal settlements, but also as mapping the area of concern itself, in the spirit of a scoping review.

6. Conclusions

With an increasing number of people living in informal settlements, spatial planning needs to address the issues of invisibility and exclusion that these areas and their inhabitants face in the planning process. In this study, we examined how the use of digital mapping affects public participation in planning processes for informal settlements in emerging economies and the Global South. We conducted a systematic literature review, for which we implemented search strings to query two major literature databases and selected relevant papers based on a carefully crafted inclusion protocol. After a brief descriptive account, we analyzed the resulting corpus, which includes case studies in developing regions, particularly Africa, followed by Asia and South America, in light of the research question. We divided the question into two components, which we reported on separately. We have also reported additional findings that we encountered in our review of the literature. We consider the latter important to better understand the broader context of the topic under discussion.

A number of the articles analyzed propose innovative approaches to digital mapping of informal settlements. Some of them advocate for the involvement of local communities throughout the process. However, a number of barriers to implementing digital mapping in informal settlements and actively engaging local communities in such efforts were identified. These challenges include inadequate access to technology, cultural and language differences, security concerns, the dynamic nature of informal settlements, and vulnerability to natural disasters. These findings echo largely what is also reflected in the literature review presented in Section 3 and thus indicate that little has changed in their regard. In addition, the literature reviewed shows that most digital mapping approaches for informal settlements are adaptable and replicable in different environments. Consequently, these approaches have significant potential for scalability, sustainability, and addressing the challenges faced by informal settlements and their inhabitants worldwide. Moreover, the use of VGI emerges as a key component of these mapping approaches, enabling rapid data generation, community engagement, transparency, and accountability.

Volunteered geographic information is an upcoming approach to mapping informal settlements and featured in ten of our reviewed articles. Whilst VGI may be promising in principle and the use of OSM understandable as it provides a ready-to-use and low-cost platform for data collection, storage, visualization, and dissemination, our review findings show that the impact of such data remains limited in terms of participation. Our findings show that the use of OSM is widespread, but at the same time there is also clear evidence that the use of volunteered geographic information by governments and authorities in the Global South has not kept pace. One such example is Kibera, which now has a strong data presence on OSM through projects like Map Kibera (Ndemo, 2020, p. 132) and is even one of the most extensively mapped areas of Nairobi. This project has been running for many years now and has led

to community empowerment in terms of skills development, community information, and building a sense of community, among other things (Ndemo, 2020; Santos et al., 2023). However, although platforms such as OSM provide a sustainable way to store and disseminate participatory mapping data, there is little evidence that policy makers in informal areas actually take it into account. In a very recent dissertation, Roza (2022) reports that in one case in Dar es Salaam, Tanzania, residents did not have the impression that the respective, participatory mapped OSM data was actually being used (p. 104). In relation to Kibera, the same work reports that government officials appeared to be more willing to engage with the OSM data originally collected via the so-called KoBo toolbox, but that they appeared to face technical barriers to hosting the collected data (p. 144). These two examples are representative of the literature reviewed, in which voluntary geographical information is often used, but there are also doubts about the extent to which the data actually feeds into planning processes in a constructive way. While platforms such as OSM potentially address a general problem outlined in Section 3, namely that mapped data should be accessible to both government officials and participants, the extent to which it can contribute to more meaningful participation in informal areas is still questionable – even 19 years after OSM's inception (at the time of writing) – partly due to the lack of corresponding legal requirements (Moreri, 2019, p. 202). In addition, volunteered geographic information platforms appear to resemble many of the challenges of other forms of digital mapping of informal areas, including the potential to trigger ownership conflicts and the requiring of certain skills, to name but a few (Hachmann et al., 2018).

An important finding that is not yet fully reflected in the literature to date is that UAVs (or drones) are increasingly being used to capture geographic data in the Global South, including informal areas. This is done in two ways: for capturing imagery or for generating 3D information either with LiDAR sensors or using photogrammetric approaches. UAVs have proven to be beneficial but also challenging in our review. For example, Gevaert et al. (2018) report a geometric accuracy of 3 cm for a case study in Kigali, Rwanda, which outperforms many satellite and aerial images and makes UAVs suitable for localized mapping. The latter is further supported by the comparatively low cost and short flight duration. Moura et al. (2021) and Moura and Freitas (2021) also report on case studies in Brazil where participants made better policy recommendations when using 2D and drone-based 3D visualizations in combination. However, Loggia and Govender (2019) report resistance from the city administration (here: Durban, South Africa) due to reservations about a possible lack of funding and capacity. The finding that drones are gaining ground in mapping informal areas should be considered in conjunction with two findings that have been recurrently reported in the literature to date: the demonstrated superiority of aerial or satellite imagery as a basis for participatory mapping (Akbar et al., 2021; DeGraff & Ramlal, 2015) and the fact that it has often been the non-geographic components of community mapping that have so far contributed positively to community empowerment and participation (Corbett & Keller, 2005). We hypothesize that the latter two outcomes are often a consequence of the rather abstract nature of mapping products. Photorealistic, map-like representations, such as images or even 3-D renderings, lower the level of abstraction and may thus provide a stronger relevance of the specific geographic components of community mapping in terms of participation. The increasing use of UAVs therefore offers great potential for mapping in informal areas, as they enable more cost-effective and timely collection of relevant data than the often more expensive aerial photography campaigns or less frequent satellite coverage. Capturing a large number of detailed images with drones and subsequent participatory mapping based on these images could therefore be a promising approach for the future. In addition, the 3D mapping potential of drones should be investigated in more detail, both in technical terms and with regard to the possible participatory effect. There is already a body of work on low-cost LiDAR devices, both drone-based and non-drone-based (e.g., Hämmerle et al., 2014; Hu et al., 2020; Klopfer et al., 2017). Similar work could be carried out systematically for the particular case of irregular and complex informal settlements.

In the literature reviewed, there is no central focus on direct participation in planning practices. Most articles focus primarily on the importance of up-to-date data and public empowerment. Nonetheless, it can generally be said that digital mapping contributes to improved collaboration among various stakeholders (which has been shown to improve the efficacy of participatory mapping in rapidly urbanizing contexts, see Brom et al., 2023) and gives local communities more of a voice, especially in the diagnosis and analysis phases of planning processes. The resulting digital maps and their creation process thus provide opportunities for people to better understand their surroundings, express their points of view, and participate in discussions (see Kovačič & Lundine, 2013; Gedgauda, 2013, for the case of Kibera). Overall, however, digital mapping approaches have not yet proven sufficient to effectively incorporate the perspectives of residents of informal settlements and grant them an active role in decision-making processes. While the research conducted shows that participation in the context of digital mapping of informal settlements currently occurs indirectly rather than directly, there is also evidence in our review that digital mapping, through careful deliberation, purposeful development, and proficient implementation, can lead to the formulation of contextually relevant and sustainable solutions that are rooted in the unique challenges and lived experiences of affected communities. It can be concluded that participatory digital mapping holds promising potential for promoting and implementing participatory planning in informal settlements, although this has not yet been fully achieved in practice and research. One of the concerns expressed years ago about the use of digital mapping was the rapid pace of technological development compared to the generally slower pace of implementation and application of participatory measures (Berdou, 2011). Our findings suggest that more than ten years after these concerns were raised, improvements in participation are still lagging behind technological developments. One reason for this could be the lack of uptake of crowdsourced data for statutory purposes such as planning. In the Global North, participation is often formalized through planning law but systematic studies for the likely fragmented Global South are not yet available. Another reason could be entrenched forces resisting a more inclusive approach, both on the part of authorities and residents (Bautès et al., 2013), regardless of the type of geospatial data collection. Our results thus suggest that digital mapping, despite its now fairly widespread (and increasing) use, is still not very effective in terms of more participatory planning.

Further research is needed to explore certain aspects of the present review. For example, the literature reviewed only includes case studies and methodologies where digital mapping of informal settlements was initiated by third parties such as governments, research institutions, and private companies. This type of approach limits the potential utility, as the solutions and mapping processes are defined by these external actors, and the complex dynamics within informal settlements may be overlooked (see also Section 3). In addition, residents of informal settlements may not have the resources or access to technology to fully participate in mapping processes, which may lead to further marginalization rather than the opposite. It would be instructive to analyze digital mapping from a different perspective, one in which informal settlement residents are the primary stakeholders in developing and defining the mapping process from the beginning and at all stages. A second point for future research is the integration of data generated bottom-up in informal settlements with officially produced data and databases. There are challenges associated with integrating these types of data, such as differences in data format, data quality, and data standards. Therefore, future research should explore effective methods for integrating bottom-up generated data with official data sources, as well as assess the quality and reliability of the integrated data. This is a current research topic in geographic information science (Liu et al., 2021; Vilches-Blázquez & Ramos, 2021), and consideration of

characteristics influenced by informality would allow another important feature to be considered in the harmonization of database schemas. The latter may lead to an improved acceptance of participatory data through enhanced compatibility with established schemes. Finally, we did not distinguish between different types of data collection purposes in our study. Most of the papers reviewed deal in one way or another with the collection of data for political planning processes. However, a more systematic differentiation into finer categories of data collection purposes could reveal further interesting insights. This should therefore be taken into account in follow-up research.

Our findings also allow us to connect to various strands of research beyond those described above. The insights we have gained can support researchers who need direct access to slums and related areas (e.g., Banerjee, 2023; Beier, 2023; Beier et al., 2021). These types of research will benefit from our findings because the respective researchers typically face informal negotiation processes with both residents and authorities to gain access to informal areas. These negotiations often exhibit elements similar to those of participation, and some of our conclusions may therefore be transferable to these areas. Another interesting potential link is made by the reoccurring method of PGIS. "[Participatory mapping] is ultimately about the sharing of knowledge and experience about place" (Brown & Kyttä, 2018, p. 6). PGIS has thus traditionally been closely associated with the link between place and GIS (Brown et al., 2020). There is a growing body of literature on this interface (Mocnik, 2022; Purves et al., 2019; Wagner et al., 2020; Westerholt, 2019) and geolocative participatory tools (practices employing such tools are sometimes referred to as 'geoparticipation', see Babelon et al., 2021; Zhang, 2019; Pánek, 2016) could benefit greatly from being place-based rather than space-based, as the former can better capture how residents conceive of their surroundings. Ultimately, place-based information could be of greater value to participation than mappable spatial information by yielding more meaningful aggregations of people's needs (Brown & Kyttä, 2018). The usefulness of the latter and the associated methods-oriented work is supported by recent findings from non-informal areas demonstrating the value of participatory mapping in capturing place values, identities, and sense of place (Gottwald et al., 2022; Pánek et al., 2020). We hope that our scoping review will help further connecting these threads motivating empirical researchers to complement the outlined findings by an informality perspective.

CRediT authorship contribution statement

Alan Américo da Silva: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **Iasmin Fernanda Kormann da Silva:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **René Westerholt:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Alina Sheikh and Haniye Hadyoon (both TU Dortmund University) for discussing with us the contents of this manuscript, which greatly strengthened the article. We also thank the anonymous reviewers for their constructive critique and comments. Open Access funding enabled and organized by Projekt DEAL.

A List of included articles

Title	Year	Outlet	Reference
Application of analytic network process (ANP), local and indigenous knowledge in mapping flood vulnerability in an informal settlement	2024	Natural Hazards	Membele et al. (2024)
Mapping riverside communities in Tefé—Amazonas—Brazil	2024	Agua y Territorio	Ventorini et al. (2024)
The SmartLandMaps approach for participatory land rights mapping	2023	Land	Lindner et al. (2023)
Questioning the practice of participation: critical reflections on participatory mapping as a research tool	2023	Applied Geography	Laituri et al. (2023)
Participatory mapping of irrigation schemes in Tanzania, Mozambique and Zimbabwe and their value for multi-level learning	2023	Agricultural Water Management	Mdemu et al. (2023)
Geo-information-enabled village level micro-planning for enhancing common good	2023	Technological Forecasting and Social Change	Singh and Chudasama (2023)
A review of the role of intermediate partners in the Community Participatory Mapping Project at Slum Upgrading Settlement	2023	IOP Conference Series: Earth and Environmental Science	Handayani and Dianingrum (2023)
A decision support tool for green infrastructure planning in the face of rapid urbanization	2023	Land	Brom et al. (2023)
A creative approach to participatory mapping on climate change impacts among very young adolescents in Kenya	2023	Journal of Global Health Reports	Logie et al. (2023)
Interrogating data justice on Hyderabad's urban frontier: information politics and the internal differentiation of vulnerable communities	2022	Information, Communication & Society	Kennedy et al. (2022)
Empowering local leaders in flood inundation mapping in Bagelen, Purworejo, Central Java	2022	Jàmbá: Journal of Disaster Risk Studies	Purwitaningsih et al. (2022)
Strategic actions of urban development to define the intervention policies of slums	2021	City, Territory and Architecture	Ragheb and El-Ashmawy (2021)
Geodesign experiments in areas of social vulnerability in the Iron Quadrangle, Minas Gerais, Brazil	2021	Land	Moura et al. (2021)
Analysis of OpenStreetMap data quality at different stages of a participatory mapping process: evidence from slums in Africa and Asia	2021	ISPRS International Journal of Geo-Information	Yeboah et al. (2021)
Using open data to detect the structure and pattern of informal settlements: an outset to support inclusive SDGs' achievement	2021	Big Earth Data	Assarkhaniki et al. (2021)
Co-creation of ideas in geodesign process to support opinion and decision making: case study of a slum in Minas Gerais, Brazil	2021	International Conference on Innovation in Urban and Regional Planning	Moura and Freitas (2021)

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Title	Year	Outlet	Reference
Community mapping with a public participation geographic information system in informal settlements	2021	Geographical Research	Vergara-Perucich and Arias-Loyola (2021)
Addressing resources to minimize COVID-19 impact in vulnerable neighborhoods using georeferencing	2021	IEEE International Symposium on Technology and Society	Dreifuss-Serrano and Cepero-Saravia (2021)
Worldwide detection of informal settlements via topological analysis of crowdsourced digital maps	2020	ISPRS International Journal of Geo-Information	Soman et al. (2020)
Visualizing life in an informal settlement of South Africa using web maps and story maps	2020	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Mdleleni et al. (2020)
Catalysing global and local social change in the land sector through technical innovation by the United Nations and the Global Land Tool Network	2020	Land Use Policy	Augustinus (2020)
Crowdsourcing and interactive modelling for urban flood management	2020	Journal of Flood Risk Management	Gebremedhin et al. (2020)
Knowledge and participation: empowering Indian urban poor to access public services	2020	International Education Journal: Comparative Perspectives	Bandyopadhyay and Nagpal (2020)
Collaborative mapping and digital participation: a tool for local empowerment in developing countries	2019	Information	Pánek and Netek (2019)
Datafication, development and marginalised urban communities: an applied data justice framework	2019	Communication & Society	Heeks and Shekhar (2019)
Racialized space: children map the post-apartheid landscape	2019	Visual Anthropology Review	Reed (2019)
Smartphone-based volunteered geographic information (VGI) for slum mapping in Pokhara City of Nepal	2019	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Ranabhat and Paudyal (2019)
A hybrid methodology to map informal settlements in Durban, South Africa	2019	Proceedings of the Institution of Civil Engineers	Loggia and Govender (2019)
Web-based participatory mapping in informal settlements: the slums of Caracas, Venezuela	2019	Habitat International	Falco et al. (2019)
A protocol for a multi-site, spatially-referenced household survey in slum settings: methods for access, sampling frame construction, sampling, and field data collection	2019	BMC Medical Research Methodology	Bakibinga et al. (2019)
Sustainable development as successful technology transfer: empowerment through teaching, learning, and using digital participatory mapping techniques in Mazvihwa, Zimbabwe	2018	Development Engineering	Eitzel et al. (2018)
Evaluating the societal impact of using drones to support urban upgrading projects	2018	ISPRS International Journal of Geo-Information	Gevaert et al. (2018)
Creating collaborative environments for the development of slum upgrading and illegal settlement regularization plans in Brazil: the Maria Tereza neighborhood case in Belo Horizonte	2018	International Journal of E-Planning Research	de Araújo et al. (2018)
Slum mapping: from space to unmanned aerial vehicle based approaches	2017	Joint Urban Remote Sensing Event	Sliuzas et al. (2017)
Upside-down GIS: the future of citizen science and community participation	2016	The Cartographic Journal	Thompson (2016)
Factors shaping cartographic representations of inequalities. Maps as products and processes	2016	Habitat International	Martínez et al. (2016)
Volunteered geographic information system design: project and participation guidelines	2016	ISPRS International Journal of Geo-Information	Gómez-Barrón et al. (2016)
A digital platform to support citizen-government interactions from volunteered geographic information and crowdsourcing in Mexico City	2016	International Conference on Computational Science and its Applications	Tapia-McClung (2016)
Community mapping in urban informal settlements: examples from Nairobi, Kenya	2015	The Electronic Journal of Information Systems in Developing Countries	Pánek and Sobotova (2015)
Open data for informal settlements: toward a user's guide for urban managers and planners	2015	Journal of Urban Management	Chakraborty et al. (2015)
Using photovoice as a community based participatory research tool for changing water, sanitation, and hygiene behaviours in Usoma, Kenya	2015	BioMed Research International	Bisung et al. (2015)
A system for household enumeration and reidentification in densely populated slums to facilitate community research, education, and advocacy	2014	PLoS One	Thomson et al. (2014)
The commercialisation of public data – How does participatory data-mining look on a global scale?	2013	South African Journal of Geomatics	Pánek (2013)
The use of GIS in informal settlement upgrading: its role and impact on the community and on local government	2003	Habitat International	Abbott (2003)

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