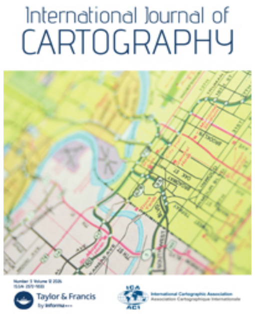

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How useful are interactive small multiples for the visualization of overlapping areal information? An expert evaluation in spatial planning

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ABSTRACT
Multidimensional spatial data is used in various application domains, such as spatial planning or risk management. The datasets are often layered within single maps, where overlapping information can create complex and potentially misleading displays. This study investigates the use of an interactive small multiples layout, where web maps with a common spatial area, each representing a different topic, are arranged side by side for simultaneous viewing. Spatial planning served as the use case, as it involves the concurrent analysis of multiple topics within a defined area. Domain experts participated in a qualitative usability study, carrying out typical planning tasks. Their feedback on the small multiples layout regarding task effectiveness, efficiency, and satisfaction (usability) was evaluated through qualitative content analysis. We learned that the layout enabled quick overviews and efficient cross-comparison between topics, particularly in the weighing of interests. All tasks were completed, and the feedback was predominantly positive. Limitations arose when the area under consideration extended beyond the boundaries of the small multiples map windows. We conclude that small multiples layouts are useful for the simultaneous visual analysis of multiple spatially coincident topics in web maps. The finding may generalize to other domains that use potentially overlapping multidimensional spatial data.

RÉSUMÉ
Les données spatiales multidimensionnelles sont utilisées pour des domaines d'application diversifiés tels que la planification spatiale ou la gestion des risques. Les lots de données sont souvent superposés sur des cartes uniques où les superpositions d'information peuvent générer des représentations complexes et parfois sujettes à mésinterprétation. Cette étude explore l'utilisation d'une mise en page interactive de petits multiples, où les cartes décrivant un même espace, chacune représentant un sujet différent, sont organisées les unes à côté des autres pour

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produire une vue simultanée. La planification spatiale sert de cas d'étude, dans la mesure où elle requiert une analyse conjointe d'un ensemble de thèmes décrivant un espace géographique donné. Des experts du domaine ont participé à l'analyse d'utilisabilité, déroulant des tâches standards de planification. Leur retour sur l'utilisation des petits multiples sur des critères d'efficience, d'efficacité et de satisfaction (l'usabilité) est évalué par une analyse qualitative de contenu. Nous avons appris que la mise en page conjointe de petits multiples permet une vue d'ensemble rapide et une comparaison croisée entre thèmes efficace, en particulier en ce qui concerne la pondération des intérêts. Toutes les tâches ont été accomplies et le retour a été en grande partie positif. Des limitations sont apparues lorsque la zone étudiée s'est étendue au-delà des limites des fenêtres des petits multiples. Nous concluons que les mises en page de petits multiples sont utiles pour une analyse visuelle simultanée de multiple sujets spatialement coïncidents. The résultat pourrait être étendu à d'autres domaines qui utilisent des données spatiales multidimensionnelles qui se superposent.

Introduction

Cartographic design of static maps, whether on paper or in digital formats like PDFs, tries to ensure that overlapping information remains cognitively legible and distinct. Typically, overlapping zones are delineated with hatching or thick borders to maintain visibility of underlying data. Many web maps allow for several spatial datasets to be combined by the user without restrictions regarding information density or layer order, potentially severely impacting the readability of the information. Interactive web maps allow the users to actively and flexibly adapt the map content to different use cases through individual settings and layer combinations (Roth et al., 2017). However, today's datasets with numerous thematical layers pose challenges: the potential for complex, densely packed maps with several overlapping layers may overwhelm users or can also lead to wrong interpretations. As the information density in a map increases, the conventional layer overlay approach becomes inadequate, often resulting in overplotting – the obscuring of individual values due to data overlap (Few, 2020) (cf. Figure 1 a). Furthermore, combining thematic layers can lead to unintended visual effects, such as misleading perceptions of combined colors or confusing hatching patterns (Tufte, 1990).

Currently, geoportals often visualize spatial data within a single map window (as shown in Figure 1a). To ensure good readability of single map displays, the number of topics to be displayed at the same time is limited. Limiting the number of topics for web map design is not appropriate for use cases that require the simultaneous visual analysis of numerous overlapping topics. Examples of such use cases can be found in the field of spatial planning: Swiss spatial planning legislation (Art. 3 of the Spatial Planning Ordinance (Raumplanungsverordnung, RPV), 2000) requires that all affected interests within a defined planning area must be identified and considered during the planning process to balance different interests.

To meet these requirements, planners need a simultaneous overview of the often congruent and numerous topics related to a planning area. For example, to protect the

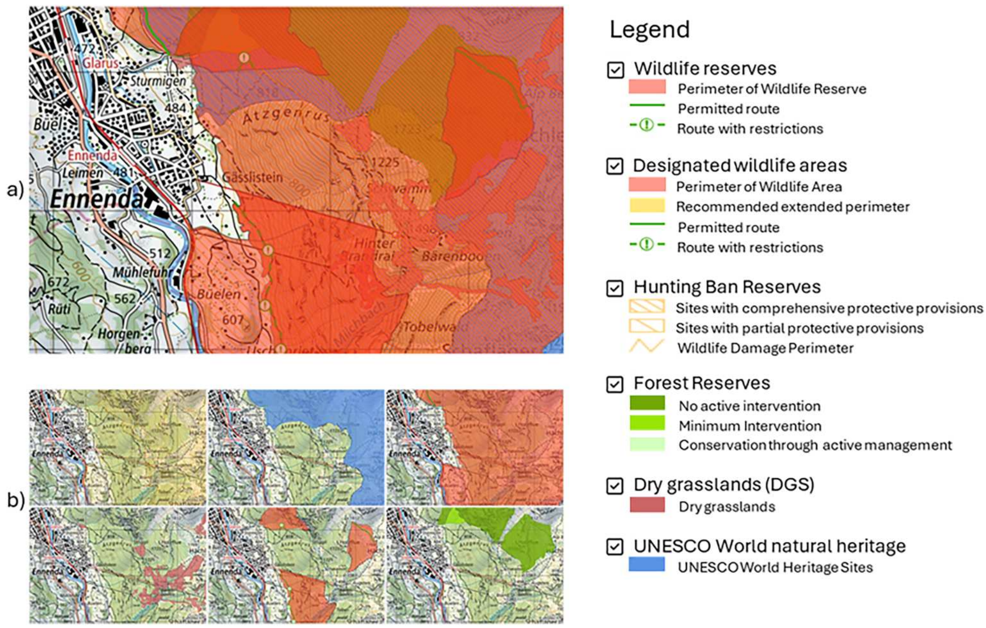

Figure 1. The map shows various topic areas in Switzerland (Glarus). The screenshots of the viewer, from which the topics are taken, only allow for a single map window, as shown in (a). As some of the topics overlap, they can no longer be properly visualized. To be legible, they would have to be individually selected and deselected in the selection menu. (b) shows what a possible small multiple representation might look like to overcome the problem of overlaps. The small multiples layout is currently not supported in the viewer where the screenshots are taken from (Fig. based on map.geo.admin.ch).

population and infrastructure, it is essential to take the expected intensity and probability of natural hazards and the associated risks into account in a planning perimeter. For this purpose, various data (e.g. known event perimeters, hydrological investigations, vulnerability analyses etc.) are evaluated in multi-dimensional hazard maps and considered in zone planning. Also, other public property restrictions must be respected during planning, such as protected nature reserves or existing or planned infrastructure for transport and utilities.

As a possible alternative to overlaying multiple spatial datasets into a single map, juxtaposing content can be advantageous for displaying, interpreting, and comparing content-dense, multivariate data (Gemignani, 2021; Lobo et al., 2015; Tufte, 2001). This form of information visualization with small multiples maps arranged side by side – so-called 'Small Multiples' (Tufte, 2001), 'Multiple Views' (Lobo et al., 2015) or 'Trellis Display' (Becker et al., 1996) – has so far mainly been discussed in the context of static images. There are already functioning concepts for combining several views, such as linking and brushing in linked views (Radoš et al., 2016). There are examples of linked multiple maps where the navigation or updates in one map window also cause changes in another window, e.g. in detail and overview maps (Khan & Khan, 2011). These are central concepts that are already widely applied and used in layouts. Although there are a few applications in practice that use interactive small

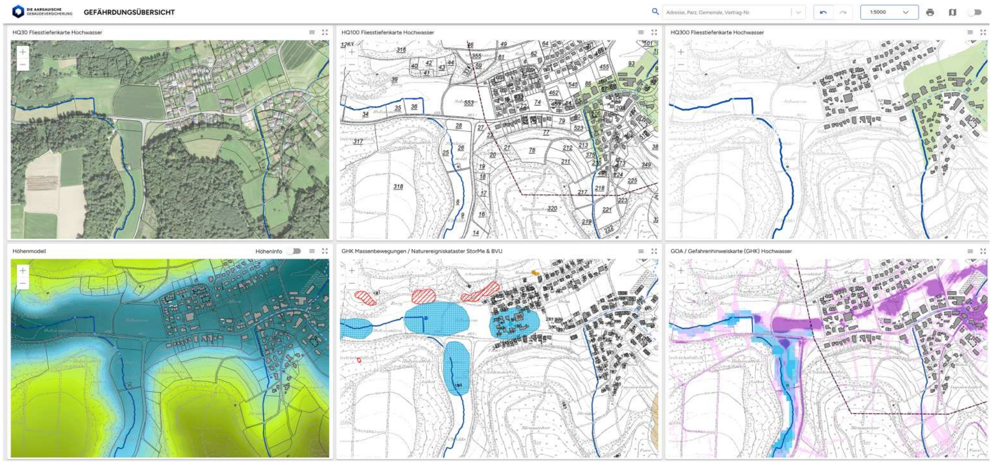

Figure 2. An example of a small multiples web map layout on the topic of risk overview for buildings from the Aargau building insurance company. The maps are used in the building permit process to identify risks posed by natural hazards (see https://die-agv.ch/static/gk/index.html) accessed: 08.07.2026.

multiples in the web map context (e.g. see Figure 2 'Aargauische Gebäudeversicherung – Gefährdungsübersicht', engl. 'Aargau Building Insurance – Risk Overview' (Aargauische Gebäudeversicherung, o.J.)), the potential of representing congruent data using interactive small multiples in a web map context for specific tasks is still largely unexplored.

Consequently, this paper presents a usability study of an interactive small multiples web map layout for displaying (multiple congruent) spatial datasets for the use case of spatial planning (where in most cases between 5–15 topics must be assessed simultaneously). The focus of the evaluation is on feedback from the practical application of the small multiples display by spatial planning experts for defined real-world tasks, such as exploring and comparing data within a specific perimeter.

Aim

This study aims to evaluate the usability of interactive small multiples to display area data in web map applications for the visual exploration of spatial information while completing planning tasks. Usability is defined 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' (Internationale Organisation für Normung (ISO), 2018). We seek to determine how well individual spatial planning specialists, being familiar with the task contexts, can interpret area information that shares spatial references (what would result in overlaps in single view maps) in interactive small multiples displays. We examine whether the use of additional visual aids, such as position indicators or area outlines, affects task success and satisfaction. From the results of the usability test, recommendations are derived for web-based small multiples layouts. From the objective, the following research questions arise:

RQ1.0: Are small multiples layouts suitable for defined spatial planning tasks within the context of a dynamic online application?
RQ1.1: Can area information with identical spatial references within a previously defined area be effectively read by individuals familiar with the usage context?
RQ1.2: Are expert users able to read the information displayed in a small multiples map with satisfactory efficiency?
RQ1.3: Are there differences in the evaluation when additional cartographic orientation aids are used (e.g. a position button or marking the perimeter in all small multiples maps)?
RQ1.4: What are the influences of different map sizes and layouts on the task completion process and results?
RQ2: What recommendations can be derived from the empirical evaluation for the use of small multiples layouts in the application scenario?

State of the art

Literature offers different solutions for the visualization of spatially overlapping information. The different layers can, for example, be displayed with transparency so that the underlying information remains visible. Hatching or only representing the outline of the area can also be chosen (cf. Figure 1). Kiik (2015) used eye-tracking to empirically investigate how well the various overlay techniques such as boundary lines, transparency, hatching and symbols could be interpreted, with hatching performing best in background recognition and transparency in polygon identification in the test (Kiik, 2015). Tufte (1990) described the technique of layering and separating complex data into individual data aspects as one of the most powerful means of presenting complex data content in an understandable way. When combining thematic layers simultaneously on a map, the layer overlay method no longer works above a certain information density on a background map, as certain information is covered by other information. Other visual composition strategies are therefore required (Lobo et al., 2015). Knura and Schiewe (2022) also identify the problem in connection with extensive heterogeneous point data on maps and the associated geometric and thematic disorder. Few (2020) refers to the problem of individual values becoming unrecognizable due to too much information being printed on top of each other at the same time as 'overplotting'. However, information visualization with transparency or hatching reaches its limits with content-dense maps, as different colors of the layers mix or other undesirable visualization effects occur (Tufte, 1990).

A different approach to comparing spatial datasets is the swipe or mixed lens method: A 'swipe' uses a slider to move the view back and forth between two map views. When visualizing with a mixed lens, a layer underneath the map is made visible in a small area under the mouse pointer. This method reaches its limits with dense content or more than two maps. Popelka et al. (2022) compared the swipe method with the multiple view. They concluded that if there are more than two maps, the use of multiple view is more effective than the swipe to compare topics in different maps (Popelka et al., 2022). As the topics in spatial planning mostly include more than two topic layers or maps, these methods do not solve the overplotting problem. With an offset lens, the information in the main map window is dynamically supplemented with information in an additional window, which also displays the location of the cursor in the main window on a different map background (e.g., aerial image). The offset is additional information that is detached from the background map and whose exact spatial assignment is only ensured with the help of graphic elements and correctly interpreted by the map reader (despite the 'incorrect geographical location' on the map). However, studies have shown that participants perform poorly with this type of visualization method (Lobo et al., 2015).

Small multiples may present a solution to these challenges. They involve replicating a view across multiple maps, each showcasing different topic layers. The literature highlights several advantages of using small multiples for information visualization. They reduce complexity while preserving a high information density, allowing multivariate information to be presented without overwhelming the reader (Gemignani, 2021; Tufte, 2001). Well-designed small multiples facilitate efficient overview and direct comparison (juxtaposition) of the information across different sub-cards, enabling quick and effective interpretation (Tufte, 2001). The uniform dimensions and shapes of small multiples allow readers to apply their understanding from one graphic to others easily, facilitating immediate comparison of differences, provided all multiples are visible at a glance (Gaigg, 2024). Additionally, small multiples are space-efficient, enabling the presentation of high data density in relatively compact formats. Despite their small size, they can convey substantial amounts of information if redundancy and context are properly managed (Tufte, 2001). However, to leverage these advantages, several challenges must be addressed in the design of small multiples. They should be arranged so that comparisons can be made at a glance, whether placed horizontally, vertically, or in a matrix (Few, 2020). All small multiples should have identical dimensions, scale, and shape to ensure consistent understanding across all graphics (Few, 2020; Gemignani, 2021). Providing a shared context and logical subcategorization is essential for efficient reading. This involves breaking down a common data set into logically categorized small multiples (Few, 2020). Each individual small multiple must be carefully designed to avoid excessive complexity, allowing readers to process information easily (Gemignani, 2021). Additionally, if possible, data should be organized in a logical sequence, such as chronological or thematic order, to enhance readability and navigation (Few, 2020; Gemignani, 2021). In terms of small multiple layouts with spatial data, these are more commonly seen in a temporal context, where each map shows a point in time and these can be compared with each other via individual tiles (see e.g. Blickle et al., 2019; Fabrikant et al., 2008) or in combination with choropleth maps (Gemignani, 2021). Small multiples are a promising method to achieve simultaneous and non-overlapping presentation of multiple spatial information layers, potentially overcoming some of the limitations e.g. of overlay methods in dense map contexts. However, there are hardly any studies on the use of small multiples for a specific practical application that requires the simultaneous visual analysis of a large number of thematic layers like in spatial planning. To examine this, studies need to be conducted to analyse the usability of the small multiples layout in different application domains.

The evaluation of user interfaces that present data in maps has already been extensively researched and is based on both empirical and analytical methods. Çöltekin et al. (2009) proposed an integrative approach to evaluating interactive map interfaces by combining standard usability metrics, namely satisfaction, efficiency, and effectiveness, with eye movement analysis. In a controlled experiment, they showed that traditional usability measurements can be meaningfully enhanced by procedural eye-tracking data that reveal cognitive load and attention distribution in spatial tasks. Roth et al. (2017) subsequently advanced the field by presenting a comprehensive research agenda for empirical user studies on interactive maps and visualizations, addressing perceptual, cognitive, cultural, and practical aspects that influence the user experience with interactive cartographic systems. Guerino and Valentim (2020) conducted a systematic mapping study in which they identified 30 different technologies for evaluating usability and user experience that are applied to natural user interfaces (systems controlled by gestures, speech, and gaze). They found that most existing technologies evaluate either usability or user experience in isolation, without considering specific interaction characteristics. Unrau and Kray (2019) provided a comprehensive overview of the literature on GIS usability evaluation, revealing persistent gaps, including the lack of specific usability guidelines for GIS, inadequate methods for analysing complex workflows, and a lack of longitudinal studies on usage. Marquez et al. (2021) attempted to address these gaps by proposing ten domain-specific usability heuristics for interactive web maps, derived through a structured methodology covering categories such as map visualization, scale, symbolism, interactivity, and responsive design. To address the methodological challenges of scalable evaluation, Unrau et al. (2022) proposed a remote evaluation approach for web-based GIS that utilizes UI interaction logging and pattern recognition techniques. In an online study with 40 participants, they were able to show that this method can effectively identify usability problems and user strategies without the cost and logistical effort of an in-person evaluation.

Method

To analyse the research questions, a small multiples layout prototype was developed based on the information from the literature. The prototype, the study design as well as the evaluation method are presented in this chapter. Firstly, we introduce the use case, which is the basis for our evaluation. The development of the prototype and subsequent user study, presented in detail in the following chapters, is based on a process (cf. Figure 3) from the International Organization for Standardization (ISO) standard 9241-210:2019 (Internationale Organisation für Normung (ISO), 2019). This norm shows international standards for the development of human-centred (re)design of interactive systems and is an iterative process.

Application area, data and use case

The application area for this user study was spatial planning with data from the ÖREB cadastre (dt. 'Kataster der öffentlich-rechtlichen Eigentumsbeschränkungen', engl. 'Cadastre of public law restrictions on ownership'). The ÖREB cadastre is a Swiss cadastral system that records public law ownership restrictions on land. Currently (as of 2024), the ÖREB cadastre at the federal level comprises 22 restrictions on property under federal law (Bundesamt für Landestopografie swisstopo, 2024). This data is important in planning and is well known to planners as it provides many relevant thematic layers. The tasks selected for the evaluation are from special utilization planning (dt. 'Sondernutzungsplanung',

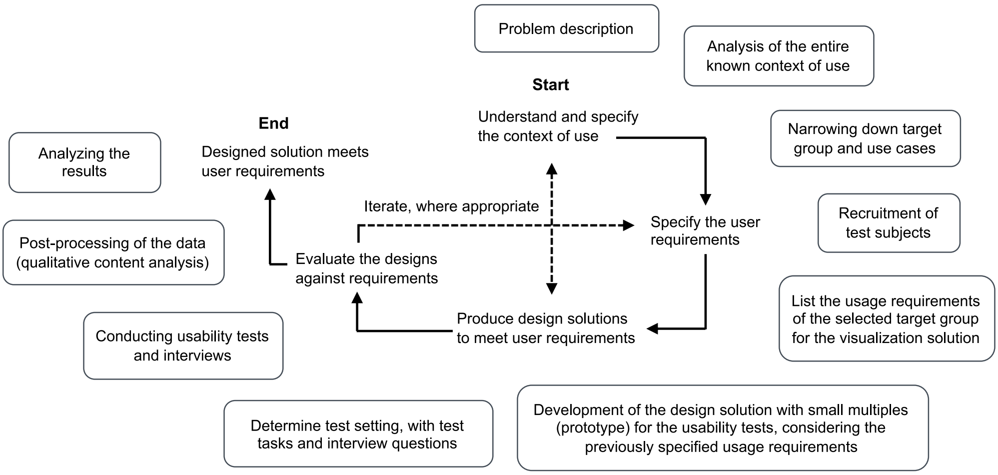

Figure 3. The process sketch illustrates the process steps recommended in ISO standard 9241-210:2019 as implemented in this study with time dependencies and possible iterations in the development and determination of design solutions (extended, based on Jacobsen & Meyer, 2017).

i.e. high-quality development of specific areas, supplementing regular planning). Such planning tasks span multiple plots and often involve several layers of the ÖREB cadastre, making them suitable for evaluating the effectiveness of small multiples layouts. The following section presents a fictitious but realistic use case based on ÖREB data in which participants are asked to complete several tasks. Based on their interactions and feedback, the prototype was evaluated:

The spatial planning legislation is the basis of the work done by planning authorities, e.g. spatial planning offices, and reviewing bodies, like building authorities. The legal requirements and procedures they follow can be extensive and complex, depending on the specific planning content and issues involved. Geoportals are not equally relevant for every planning step, but all planning processes must adhere to the formal procedures outlined in Article 3 RPV (dt. 'Raumplanungsverordnung', engl. 'Spatial Planning Ordinance') (Raumplanungsverordnung (RPV), 2000), which include identifying, assessing, and balancing all relevant interests. As a result, basic analysis of all relevant topics in relation to a plot or area is a crucial component of every planning process. To illustrate the planning process, we consider a fictional scenario involving a spatial planning specialist. The specialist is commissioned by a city to create a design plan for a 5-hectare site. The first step involves reviewing the applicable legal restrictions and identifying affected interests by accessing the ÖREB cadastre, examining the relevant urban district. The specialist reviews the displayed topics and, if necessary, requests further details, such as legal provisions for specific areas. These considerations must be integrated and balanced in the planning process. The specialist documents the relevant impacts, either through notes or screenshots. Depending on the focus of the planning, additional data, such as public transport stops, may be obtained from other geoportals. All this information is compiled, documented and used as a foundation for developing the project idea and design scenarios in consultation with the client. Other development phases, which include creating analog sketches, neighborhood models, or other 3D visualizations, as well as on-site inspections and stakeholder discussions, are conducted independently of the web map application. As the project progresses and detailed planning continues, specific aspects are rechecked in the geoportal, such as infrastructure locations, existing trees or flood risks. Plot numbers and land ownership details become particularly relevant as the planning process enters the participation phase. The completed plan, along with a report analysing the initial situation and the balance of interests, is submitted to the responsible authorities for review and approval. The authorities ensure compliance with formal planning principles and relevant regulations, following similar principles as those used in the planning process. The example process described here is based on various cantonal guidelines (e.g. Güntert et al., 2016; Wetzel & Amt für Raumentwicklung Kanton Schwyz, 2019) and is not complete, as procedures and requirements can vary between cantons but serves as a basis for the prototype design and evaluation task definitions.

Prototype design

The prototype for this study is an interactive web map application utilizing small multiples, where several maps are juxtaposed. Each map displays a different thematic layer with, potentially, several data levels or categories. The evaluation focused on the target group of spatial planning professionals with tasks as described above. The process and task description allows for inferring the key requirements of the small multiples layouts:

- Supporting spatial planners in identifying and assessing interests within a planning area is essential. Facilitating the comparison and weighing of various topics is important.
- Displaying several topics simultaneously in a predefined perimeter/ area. The focus is not on the individual property, but on an entire planning area.
- Allowing interactive selection of topics by users: Different topics can be combined with each other and displayed or hidden in any combination.
- Representing the spatial relation of the topics through geometry
- Displaying or allowing the querying of additional attributes and detailed information
- Maintaining user understanding of their actions and responses (Krug, 2014)

These requirements were implemented in a prototype developed using Axure software (Axure Software Solutions, 2024) and QGIS (QGIS Development Team, 2024). Axure allows creating and optimizing graphical elements through simple drag-and-drop functionality. QGIS was utilized to generate the map contents. Two layout variants of the small multiples web map layout were created. Thus, participants compared two small multiples layouts implicitly with the single-view geoportal they were familiar with. The layouts were: 'Layout 1' with three small multiples maps per row (cf. Figure 4 left) and 'Layout 2' with four maps per row (cf. Figure 4 right). Additionally, two versions of Layout 1 were implemented, one with and one without a perimeter marking (black border) of the evaluation area to test if such markers help user orientation.

The prototypes allowed synchronized navigation across multiple maps by clicking plus or minus symbols (zooming) and clicking and moving (panning). This ensured that all small multiple maps remained identical in terms of size, shape, and scale. The functionality to zoom inside the maps with the mouse wheel was removed due to conflicts with page scrolling. The conflict between scrolling and zooming with the mouse wheel is not only a problem with small multiple layouts, but also with web maps, especially if they take up a larger area of the website (see, for example, https://leafletjs.com/). There are workarounds (e.g. 'Ctrl + scroll'), but there is still a need for further testing of this type of workaround in combination with small multiples. The prototype included 12 small multiple maps, each with five zoom levels implemented to provide some zoom experience, with the largest zoom level utilizing the official cadastral survey map as the background. The restriction to discrete zoom levels was due to technical limitations of Axure RP. Since the software does not support the implementation of fully functional web-based map applications, but only allows the simulation of web map behavior, continuous zooming could not be implemented within the prototype environment. Thus, the available zoom levels are a replication of the zoom levels typically offered by geoportals. By deciding on 12 small multiple maps, a sufficiently large number of small multiple cards were selected so that all maps could be viewed in a single layout using only page scrolling. This was important because the behavior of the participants was to be studied. However, the tasks were not allowed to exceed a certain level of complexity to stay within the time frame of the tests, so the number of topic cards was limited. At the same time, the tasks should challenge the networked thinking and reactions of the spatial planning experts. A middle ground was sought by selecting 12 frequently occurring, well-known ÖREB topics in spatial planning. The map content, including ÖREB data and background maps, was integrated into QGIS via WMS services of the geodata infrastructure of the federal government and the canton (Bundesamt für Landestopografie swisstopo, 2021). The color schemes for map content adhered to federal standards (i.e. the topic symbolisations were replicated as they are usually available in standard geoportals), using grayscale background maps to avoid color conflicts with the ÖREB data.

The legend of each tile was placed on the right side of each map and always visible (as suggested by Edler et al., 2020). Fixed visibility avoids dynamic or collapsible formats and subsequent visual changes from moving or resizing content. Buttons and icons were kept to a relevant minimum to prevent cognitive overload as suggested by Jacobsen and Meyer (2024). Standard geoportal functions such as searching or clicking on objects were not fully implemented in the prototype, as these were not in the focus of the evaluation.

The following subchapters present the structure of the study, starting with a description of the target group, recruiting expert users, the study procedures, and the data analysis.

Participants and recruiting

In advance of recruitment, an ideal user persona was described to ensure the selection of test participants according to uniform criteria: professionals with an educational background as well as several years of experience in spatial planning, and proficiency in using maps and geoportals. The persona's computer skills and familiarity with the ÖREB data and planning tasks were considered essential for this study. Care was taken to ensure that the participants were familiar with special utilization planning, the task chosen for this evaluation, from their everyday work. Age and gender of the participants were not considered important if the professional expertise was met. The user study included six expert participants. Information from six participants is able to detect the majority of problems and is tailored to the specific expert context of use to ensure a relevant and comprehensive understanding of user interactions (Jacobsen & Meyer, 2024).

Study procedure

The study was conducted in an existing usability laboratory, equipped with a standard office setting including a screen with standard resolution (cf. Fig 3). The lab allows participants to be observed discreetly and unobtrusively as they complete the tasks. The procedure involved a welcome and introduction for each expert participant, then the completion of defined planning tasks with the prototypes, followed by an interview to gather qualitative data on the designs (Geis & Tesch, 2019). In welcoming the participants, the organizational process of the tests and interviews was explained to them and data protection concerns were clarified. With a few casual small talk questions about their everyday work, the experts were 'warmed up' to the topic of spatial planning. The introduction to the topic included questions such as 'What kind of spatial planning work do you do?' and 'How do you use the ÖREB cadastre or cantonal geoportals in your daily work?'

Afterwards, the participants completed defined planning tasks and were encouraged to think aloud (Lewis & Rieman, 1993; Vanicek & Popelka, 2023) while doing so. Both layout variants were used one after the other for completing the planning tasks. At the start of the planning task, participants were informed of their role and the context in which they were operating ('Please imagine the following situation/role: You are a spatial planner from the private sector, … ') as well as the steps they were to carry out. The tasks included i. a. exploring a planning area and identifying public-law property restrictions, deriving planning recommendations while taking various spatial interests into account, as well as recognizing and linking information from multiple maps. In addition to effectiveness (e.g. correct identification of themes and attributes), the focus was on observing usage behavior, intuitive navigation, and the participants' spontaneous reactions. After the main planning task, hypothetical interactions were explored (e.g. data queries, layer control, map customizations: 'If you're not interested in one of the topics shown, how would you turn it off?', 'How would you add more topics?') to capture users' expected operational logic and mental models (see https://go.fhnw.ch/5miykb 'Description of the user test procedure' for detailed user test script).

The task's completion was observed by the researcher to assess the effectiveness, satisfactory efficiency and overall satisfaction of the participants using the interactive small multiples layout. Task completion was not assessed by recording the completion time, as participants were not encouraged to complete the tasks as quickly as possible but to complete them as they would in their everyday work. When measuring efficiency in test procedures, various parameters must also be considered, such as learning effects and familiarization effects with a new interface, which only occur after a certain number of test items have been solved (Jacobsen & Meyer, 2017). Effectiveness was assessed by asking participants to report verbally on relevant topics. Efficiency and satisfaction were evaluated through spontaneous feedback and post-interview questions regarding the usability and suggested improvements to the layout. To test the impact of the marked perimeter on orientation, participants completed tasks with and without the markings. Feedback on the markings' effectiveness was collected during and after the tasks. The compatibility of the prototype with other essential web map functions used in spatial planning was also analysed through theoretical questions posed after the practical tasks. The usability tests, as well as the post-interview, were video recorded for analysis reasons, and results were pseudonymized. In order to distinguish between the test subjects' real experiences and their speculative hypotheses, which cannot be verified by concrete usability tests or surveys, the usability tests were carried out before the interview so that real experiences could be inquired about in the interview (Krug, 2014). The entire procedure took between 1.5 and 2 h for each participant.

Qualitative content analysis

The video material collected during the usability tests and interviews was transcribed using MAXQDA software (VERBI – Software. Consult. Sozialforschung. GmbH, 2024). The transcription process involved converting the spoken content of the test subjects into written form, ensuring that statements were transcribed completely and verbatim. Swiss German statements were translated to standard German. Following transcription, qualitative content analysis (Mayring & Fenzl, 2019) was conducted. This involved systematically categorizing relevant text passages using a predefined coding guide, like difficulties / problems when using the interface, positive feedback on the layout/prototype, negative feedback on the layout/prototype (see https://go.fhnw.ch/5miykb). The qualitative content analysis included the general positive and negative feedback, any problems or uncertainties the participants encountered, and their overall sensitivities while actively working with the prototype. Additionally, the subjects' opinions and expectations regarding the efficiency and effectiveness compared to existing systems were considered in the analysis.

Results

The following subchapters present the collected results from the study related to the interactive small multiples layouts in general and the comparison of the two tested layouts.

Feedback on the small multiple layouts

The interactive small multiples layouts received to some degree positive feedback from all six test subjects. Such approval was noted both spontaneously during the tests and in post-interview sessions when participants were asked about their preferences. Participants described the layout as 'pleasant', 'good', 'practical', and 'useful' for quickly gaining an overview of displayed topics or for making comparisons. One task required participants to identify all public-law property restrictions within a defined area. The results showed that at least one participant recognized each topic, and no topic was missed by all participants. The topic map 'zone plan overlays' was difficult to read due to its complexity and symbolization issues as it shows several layers within the same topic (which is a characteristic of the data used and was not changed for the evaluation). This additionally confirms that even in small multiples design, each topic should have none or few overlapping contents to aid readability. Task completion also revealed other issues affecting map readability, such as, misidentified or generalized topics by single participants, technical limitations that distracted from the content, and four participants expressed difficulties in discerning the map colors (which were not changed but implemented according to the standards). While this study is not a comparative analysis and cannot contextualize these issues, it is likely that similar problems occur with other types of display, especially also as the color schemes used for the topics were the same as already in use for the ÖREB data in current geoportals. However, the small multiples layouts, with its partially duplicated information across maps (i.e. backgrounds), caused confusion for some participants. But observations during task completion revealed that participants were able to effectively integrate and combine information from multiple maps. They combined between three and six topics from the corresponding small maps and consistently included the background map to gather additional details, such as the presence of trees or building structures. This observation is supported by feedback indicating that the small multiples layouts were particularly effective for making cross-comparisons between different map contents. Three participants specifically noted that the layout was more effective than other geoportals they had used for quick cross-comparison. One participant highlighted that the parallel arrangement of topics in the small multiples layouts allowed for targeted, detailed queries without unintentionally selecting overlapping objects.

All participants successfully completed the tasks for both layouts. Some participants had difficulties with the prototype until they adapted to the synchronized zoom and movement features. One participant described the small multiples layout as 'taking a bit of getting used to', while another found it 'intuitive to use'. Half of the participants (three out of six) expected to zoom within a small multiples map using the mouse wheel. One participant stopped attempting to zoom due to this unmet expectation and needed a reminder to use the plus and minus icons. The zooming method using the plus and minus icons was viewed as disadvantageous because it required moving the mouse toward the icons, whereas participants expected smoother transitions through scrolling.

Comparison of the two developed layouts

Some participants noted that the maps in the small multiples layouts were 'for certain work steps somewhat small.' Despite this, one participant stated that the information was readable in both layouts, and another described both layouts as suitable. Two participants did not realize two different layouts were tested and could not comment, as they were deeply focused on their spatial planning task that they did not realize that the small multiples layouts also changed when they switched between the two tasks. The remaining four preferred Layout 1 over Layout 2 or depending on the work step, with two finding Layout 1 generally more pleasant and Layout 2 more difficult, but potentially preferable for specific work steps since more topics are visible at the same time. When using the small multiples Layout 1 for the first time, not all participants intuitively scrolled down to view the additional topic maps. Two participants needed to be informed about the scrolling function: one attempted to complete the first task without scrolling and viewing the additional topics, and the other proactively inquired about additional topics. One participant mentioned that the layout lacked visual cues for scrolling. In general, one stated that Layout 1 is better suited for comparing details and another is better suited for finding your way around an unfamiliar area for the first time. Layout 2 was described by two participants as well suited to getting a rough overview of all topics in familiar surroundings, but it is more difficult to orient oneself as the small map sections restrict the overview of the area (3 participants out of 6). At the same time, both layouts are completely sufficient for viewing a single plot of land, even at a high zoom level, if one does not have to navigate much (1 out of 6). However, both layouts are too small for querying small-scale information about an entire area (4 out of 6). If an entire area or a neighborhood is to be viewed at a high zoom level, only a fraction of the surrounding area can be seen on such a small map. It is then not possible, for example, to view the entire perimeter area simultaneously on a high-resolution cadastral survey map (cf. Figure 5). Moving the map section back and forth in the map window to see the whole perimeter was perceived as a disadvantage (4 out of 6). In this context, any performance problems (e.g. a delay when moving the map) are also more significant (1 out of 6).

General feedback

Five out of six participants Figure 5 looked for an option to actively select topics in the prototype. However, due to the prototype's nature, this selection menu was only hinted and not fully implemented. Participants generally expressed concerns about the risk of overlooking important planning topics. They pointed out that even with current tools like accordion menus, there's still a danger of missing critical themes. Two participants stated that selecting themes with checkboxes in accordion menus as common in conventional web maps is time-consuming once the theme selection is large. They also noted difficulties in finding specific topics through search functions that required exact names. Many participants typically rely on pre-selected topic ranges stored in geoportals

Figure 4. Layout 1 (left) is 12 maps laid out in a 3 × 4 grid. As only three maps are displayed per line, they are larger (15 × 10 cm per card) than in Layout 2 (11 × 7 cm per card), but the users must scroll down to view all cards. This prototype is accessible at https://go.fhnw.ch/V9Ce4F. Layout 2 (right) is also 12 cards arranged in a 4 × 3 grid. With standard desktop resolutions (16:9 aspect ratio, 24-inch screen with 1920 × 1080 resolution), all 12 cards are displayed simultaneously without having to scroll. To fit the screen, these maps are smaller than in Layout 1. This prototype is accessible at https://go.fhnw.ch/p5MaCz.

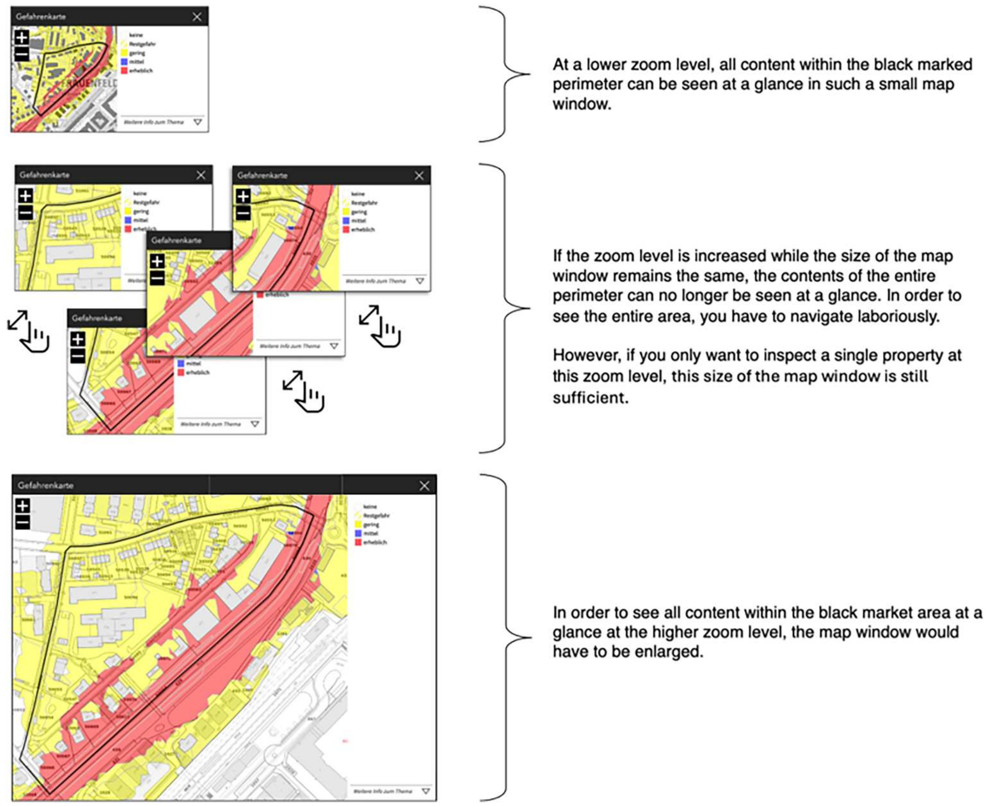

Figure 5. Visual explanation of the zoom level problem. The 4 × 4 map block represents the fact that if the map window size remains small but the zoom level is increased, the map section must be moved around at least four times to see the entire perimeter. The bottom illustration shows how much the map window would hypothetically have to be enlarged if the zoom level is increased so that everything is visible again at once.

or use checklists to manage topic selection. Participants suggested an approach where for a defined spatial perimeter a query would list all affected topics. This method, like plot-by-plot queries in the ÖREB-cadastre, would allow users to see which issues are present within a perimeter at a glance. One participant mentioned the usefulness of displaying 'unaffected' topics as well.

Participants reported difficulties with orientation when navigating at a high zoom level, especially in unfamiliar areas. The small map sections led two participants to navigate 'offside' and lose track of their position relative to the perimeter. One had to zoom out to re-target the perimeter, while the other noted that the juxtaposition of maps helped with orientation. However, this problem of losing spatial context is known and does not only occur with small multiples layouts (see e.g. Bartling et al., 2022; Chen & Li, 2020; Hollenstein & Bleisch, 2022) and would have to be tested further in consideration of this literature. The marking of the planning perimeter received positive feedback. Almost all participants noticed and spontaneously commented on the perimeter marking. The background map was mentioned for providing a clear thematic background for all maps and for increasing its level of detail when zooming in.

In the post-interview, most participants (4 out of 6) initially reported no unexpected functionality of the layout or problems while using it. Upon further inquiry, all mentioned some difficulties or problems encountered during the tests: The prototype had limited functionality and performance, which was criticized by several participants. There was uncertainty about which interactions were possible, leading to attempts and subsequent abandonment of certain actions (e.g. entering search terms). The inclusion of more functions and smoother performance was desired.

The inability to request detailed information about objects on the themed maps hindered technical expertise and was criticized. A possibility of using the selection menu was also missed. These issues are technically solvable problems that arose due to the limited functionality of the prototype.

Prerequisites for successful use

Two participants found it challenging to comment on efficiency due to feeling insecure and slowed down by the unfamiliar test situation and the time needed to acclimate to the new layout. The remaining four participants reported completing the tested tasks as efficient, if not faster compared to other geoportals they had used (as far as they could judge without doing the tasks in other settings). All participants believed that certain work steps within tasks could potentially be more efficient with the small multiples layouts compared to familiar geoportals with a full-screen map. They noted that the tested layouts allow for quick initial overviews of simultaneously occurring topics at a location, assuming appropriate topic preselection. Additionally, cross-comparisons between different topics are easier and potentially more efficient with small multiples because selected topics and their legend entries are visible simultaneously. The small multiples layouts of all topics displayed side by side reduce the need to select and deselect individual layers or superimpose them in a meaningful order, saving time and mental/cognitive effort. Several participants expressed a strong desire to quickly switch between a full-screen view and the small multiples overview without losing their settings. They also would find it useful to start with a full-screen view for initial spatial orientation before transitioning to the small multiples layouts. Most participants (5 out of 6) preferred having the option to choose among three or four layout variants with different map sizes. This flexibility was considered essential for adapting the small multiples layouts to various work steps, screen sizes, resolutions, and personal preferences, thus enhancing its value in daily work.

However, all participants emphasized that the benefits of an interactive small multiples layout could only be fully realized under specific conditions, with their effectiveness depending largely on the overall functionality of the interface. While all participants provided some positive feedback on the small multiples layout, they also highlighted several prerequisites for its meaningful integration into everyday work. They noted the necessity of an efficient topic selection function, such as a menu, predefined modes, or a login feature to mark favorites. Once a set of topic maps (small multiples) is selected, it should be retained even after the application is closed and be readily accessible when needed. Participants expected to have a choice between various small multiples layouts with adjustable map sizes, allowing for intuitive and easy switching between these layouts and a full-screen view. The previously defined selection of small multiples should be saved to enable quick toggling between views. Additionally, there should be an option to access more detailed information about an object by clicking on it within the small multiples layout, such as links to legal documents or other relevant information.

Discussion

Small multiples layouts

Summarizing the presented results suggests that small multiples layouts should be given greater consideration for interactive web maps. Comparing and linking different topics is a recurring theme in a wide range of disciplines, not just planning. The small multiples layouts are particularly useful for tasks that require a quick overview of several overlapping topics. The interactive small multiples layouts offer the advantage of a logically structured, thematically separated query of detailed information without requiring users to leave the overview of all selected topics. This approach prevents the common issue of listing all details of overlaid themes upon selecting an object, allowing for more specific queries of desired information. This feature, combined with the ability to customize the map section, background map, and topic selection, supports the high data density with minimal space requirements, like in static small multiples. However, small multiples might hinder tasks that require a full-screen thematic map, such as initial large-scale orientation in an unfamiliar planning area. Therefore, small multiples should be considered a supplementary view rather than a replacement for full-screen maps. While satisfaction with reading map contents was high, effective identification of all topic details was not always achieved. Effective content reading was successful at the zoom level of single properties and sub-areas within the 5-hectare perimeter, but not all topics within the total test area were effectively read by all participants. This could address difficulties in reading map contents and aligns with ISO standard 9241-210:2019, which emphasizes that technology should support users' needs based on their limitations, preferences, and expectations, contributing to barrier-free design.

Answering the research questions

Based on the presented results of the small multiples layouts evaluation and the discussion, we answer the initially posed research questions as follows:

RQ1: Are small multiples suitable for a clearly defined spatial planning application within the context of the dynamic online application to resolve the design problem of 'overplotting' on interactive digital overview maps? Partially, yes. For a spatial planning application, specifically for a special land use planning case covering approximately 5 hectares, small multiples are effective for certain tasks by mitigating the issue of overplotting. However, they are not universally suitable for all tasks within this application. They are suggested as a complement rather than a replacement for traditional full-screen map designs. Small multiples are particularly effective for tasks requiring direct comparisons between different themes or an initial overview of site impacts, such as preliminary data collection or assessing interests within a planning area. Conversely, they are less effective for tasks that require viewing a single thematic map in full-screen, such as initial large-scale orientation in an unfamiliar area, or for high zoom-level tasks where the entire perimeter is relevant, as navigating a reduced map window can be cumbersome. Moreover, graphical optimization of individual small multiples is needed to avoid issues like internal overplotting within single maps.

RQ1.1: Is area information with identical spatial references within a previously defined area effectively readable by individuals familiar with the usage context? Partially, yes. Information was effectively readable in specific sections of the perimeter or on individual plots, but the readability of all themes at the highest detail level across the entire 5-hectare perimeter was not fully achieved. The issues related to viewing all details at high zoom levels suggest that an automated query function listing all relevant topics within a defined area could address these limitations.

RQ1.2: During usability tests, can the information displayed in a small multiples map be read with satisfactory efficiency? In other words, can the test tasks be satisfactorily completed as a whole? Yes. Participants generally found the side-by-side presentation of themes to be pleasant, effective, and practical. While some dissatisfaction arose from prototype limitations and technical issues, overall efficiency was expected to improve in daily work for certain work steps compared to the traditional full-screen approach.

RQ1.3: Are there differences in the evaluation when additional cartographic orientation aids are used (e.g. a position button or marking the perimeter in all small multiples maps)? Yes. Marking the perimeter significantly enhanced orientation within the maps. Although tasks could be completed without these aids, switching background maps could complicate orientation. Therefore, marking the perimeter proved beneficial and increased user satisfaction.

RQ1.4: What are the influences of different map sizes and layouts on the task completion process and results? The two small multiples layouts presented differed in their layout arrangement (4×3 and 3×4) and the resulting differences in the size of the individual maps. In the 3×4 layout, this added the need for scrolling to view all maps. Since two participants did not even notice that two different layouts were being tested, this could indicate that, in the case tested here, the size or layout is not a decisive factor. The two different layouts therefore do not appear to differ significantly; however, some participants initially overlooked the additional topics in the 3×4 layout, an issue that was resolved by the hint to scroll. There were, however, requests for individual customizations, such as the ability to switch between layouts.

The results support the recommendation from literature that individual maps should not exceed a certain complexity level to maintain readability across the small multiples overview (Gemignani, 2021). The prototype (Layout 1) demonstrated effective cross-comparison between map contents, even when maps were not visible simultaneously but scrolled into view. However, scrolling requires cognitive effort to remember the placement and content of invisible maps. Critical feedback was received regarding cognitive load with future, potentially larger, collections of topics.

The results indicate that participants were generally concerned about the potential to overlook important planning topics, both in the prototype and with current tools like accordion menus. This highlights the need for a more intuitive and comprehensive topic selection process not only in small multiples layouts but also in current geoportals. The suggestion to possibly incorporate external sources like Google Maps reflects a desire for a more holistic view within a single portal. This integration could reduce the need for multiple geoportals and streamline the planning process.

Navigation difficulties at high zoom levels, particularly in unfamiliar areas, suggest that users may benefit from starting with a larger map window for orientation before switching to more detailed views. The positive feedback on the perimeter marking and the background map's clarity indicates that these features are valuable for helping users maintain spatial awareness and effectively interpret map data.

RQ2: What recommendations can be derived from the empirical evaluation for the use of a small multiples layouts in the application scenario? Recommendations include offering customizable features such as zoom levels and map sections, adjustable theme selections, and controllable map sizes and positions. To maximize the value of small multiples, functionality should include detailed queries for individual objects, automated lists of all relevant topics within a defined perimeter, options for different background maps, and general functionalities like data export, measurement tools, and perimeter drawing. Investing in high-quality graphic design and ensuring good application performance is also recommended.

Only six experts could be recruited for this study, which is a limitation that can largely be attributed to the difficulty of recruiting experts. However, we also refer to Jacobsen and Meyer (2024), who conclude in their study that in qualitative tests, around six people can identify most of the problems that arise. As a next step, it would be necessary to repeat the study with a larger selection of experts in order to verify and expand on the findings already collected.

Within the scope of this work, the focus was placed on zonal data from ÖREB, as most of the ÖREB datasets are areas and therefore the problem of multiple overlaps occurs very frequently. In the next steps, lines and points must be included to a greater extent and be evaluated to determine whether there could be further or different results in this context. Additionally, the topic symbolizations were implemented as defined by the standards. Future work could include optimizing topic symbolization for use in small multiples layouts.

Conclusion

This study was motivated by the problem of information occlusion due to overlaying thematic layers of multidimensional spatial data in single web map displays. Using defined, generic, but rather complex tasks typical for visual analysis of a range of topics regarding a specific area in a spatial planning process, the usability of small multiples layouts was evaluated. While completing the tasks and answering interview questions, the expert users of the prototype revealed potentials and challenges of the small multiples layouts for visually analysing several spatial coincident topics.

The study showed that the experts responded positively to the small multiples layouts, which were unfamiliar to them before the study, and were able to complete their tasks efficiently. The fact that the experts first had to learn the new visualization and find the limits of the prototype meant that they needed a short familiarization phase at the beginning. However, as the majority continued to express positive opinions in the interviews after the tasks, it can be assumed that with more widespread use of such layouts in web applications, working with them will be more intuitive. Many of the mentioned problems were related to technical aspects that were not fully implemented in the prototype but would be available in a working system, such as a search function. Other comments concerned the less-than-optimal color systems of the ÖREB data that were implemented the same as in existing applications. These issues would have to be evaluated and assessed separately from the small multiples layouts. Within the small expert group of six participants, many advantages regarding the layout were recorded. We conclude that small multiples layouts are useful for simultaneously visually analysing several spatially coincident topics at once, as tested with and common in spatial planning tasks. These findings may be transferable to other application domains where multidimensional spatial data is employed, such as the mapping of natural hazard risks.

While this study evaluated small multiples layouts, we do not assume that such displays will replace other displays. However, they could be used in combination in visual analysis systems that offer different views on the same data, to allow expert users to select the most efficient view for a specific work step within a task.

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Author contributions

CRediT: **Salome Reutimann:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing; **Carolin Bronowicz:** Writing – original draft, Writing – review & editing; **Susanne Bleisch:** Project administration, Supervision, Writing – review & editing.

Ethics Statement

The study was conducted in accordance with the Ethical Principles of Psychologists and Code of Conduct of the American Psychological Association (https://www.apa.org/ethics/code). All participants were informed about the purpose of the study, that participation was voluntary, and that their pseudoanonymity would be guaranteed. Their consent has been obtained in written form. Approval of the study design was granted by the MSE Student Research Board of the School of Architecture, Construction and Geomatics, FHNW University of Applied Sciences and Arts Northwestern Switzerland.

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References

Axure Software Solutions. (2024). Axure RP [Computer software]. https://www.axure.com/.

Bartling, M., Resch, B., Reichenbacher, T., Havas, C. R., Robinson, A. C., Fabrikant, S. I., & Blaschke, T. (2022). Adapting mobile map application designs to map use context: A review and call for action on potential future research themes. *Cartography and Geographic Information Science*, *49*(3), 237–251. https://doi.org/10.1080/15230406.2021.2015720

Becker, R. A., Cleveland, W. S., & Shyu, M.-J. (1996). The visual design and control of trellis display. *Journal of Computational and Graphical Statistics*, *5*(2), 123–155. https://doi.org/10.1080/10618600.1996.10474701

Blickle, P., Erdmann, E., Gortana, F., Mast, D. M., Stahnke, J., & Tröger, J. (2019, December 10). Klimawandel: Viel zu warm hier. Die Zeit. https://www.zeit.de/wissen/umwelt/2019-12/klimawandel-globale-erwaermung-warming-stripes-wohnort.

Bundesamt für Landestopografie Swisstopo. (2021). Web Mapping Services WMS: Verfügbare Dienste und Daten. https://www.geo.admin.ch/de/wms-verfuegbare-dienste-und-daten.

Bundesamt für Landestopografie swisstopo. (2024). Die wichtigsten öffentlich-rechtlichen Eigentumsbeschränkungen (ÖREB). https://www.cadastre.ch/de/bereiche-oereb-kataster.

Chen, C.-H., & Li, X. (2020). Spatial knowledge acquisition with mobile maps: Effects of map size on users' wayfinding performance with interactive interfaces. *ISPRS International Journal of Geo-Information*, *9*(11), 614. https://doi.org/10.3390/ijgi9110614

Çöltekin, A., Heil, B., Garlandini, S., & Fabrikant, S. I. (2009). Evaluating the effectiveness of interactive map interface designs: A case study integrating usability metrics with eye-movement analysis. *Cartography and Geographic Information Science*, *36*(1), 5–17. https://doi.org/10.1559/152304009787340197

Edler, D., Keil, J., Tuller, M.-C., Bestgen, A.-K., & Dickmann, F. (2020). Searching for the 'Right' legend: The impact of legend position on legend decoding in a cartographic memory task. *The Cartographic Journal*, *57*(1), 6–17. https://doi.org/10.1080/00087041.2018.1533293

Fabrikant, S. I., Rebich-Hespanha, S., Andrienko, N., Andrienko, G., & Montello, D. R. (2008). Novel method to measure inference affordance in static small-multiple map displays representing dynamic processes. *The Cartographic Journal*, *45*(3), 201–215. https://doi.org/10.1179/000870408X311396

Few, S. C. (2020). *Now you see it—An introduction to visual data sensemaking*. Analytics Press.

Gaigg, M. (2024). Map UI patterns—small multiples. https://www.mapuipatterns.com/small-multiples/.

Geis, T., & Tesch, G. (2019). *Basiswissen usability und user experience*. dpunkt.verlag GmbH.

Gemignani, Z. (2021). Better know a visualization: Small multiples. https://www.juiceanalytics.com/writing/better-know-visualization-small-multiples.

Guerino, G. C., & Valentim, N. M. C. (2020). Usability and user experience evaluation of natural user interfaces: A systematic mapping study. *IET Software*, *14*(5), 451–467. https://doi.org/10.1049/iet-sen.2020.0051

Güntert, A., Hanselmann, V., Lauer, A., Oliver, G. S., Thomas, S., & Abbildungen, W. (2016). Planungshilfe quartierplanung. Amt für Raumplanung Kanton Baselland. www.arp.bl.ch.

Hollenstein, D., & Bleisch, S. (2022). Gaining overview with transient focus+context maps. *International Journal of Cartography*, *8*(1), 118–132. https://doi.org/10.1080/23729333.2021.1960139

Internationale Organisation für Normung (ISO). (2018). ISO 9241-11:2018. https://www.iso.org/standard/63500.html

Internationale Organisation für Normung (ISO). (2019). 9241-210:2019. International Organization for Standardization.

Jacobsen, J., & Meyer, L. (2017). *Praxisbuch Usability und UX - Was jeder wissen sollte, der Websites und Apps entwickelt (3. Auflage)*. Rheinwerk Verlag GmbH.

Jacobsen, J., & Meyer, L. (2024). *Praxisbuch Usability und UX - Was alle wissen sollten, die Websites und Apps entwickeln (4. Auflage)*. Rheinwerk Verlag GmbH.

Khan, M., & Khan, S. (2011). Data and information visualization methods, and interactive mechanisms: A survey. *International Journal of Computer Applications*, *34*, 1–14.

Kiik, A. (2015). *Cartographic design of thematic polygons: A comparison using eye- movement metrics analysis (Issue 337)*. Lund University, Department of Physical Geography and Ecosystems Science. https://www.lu.se/lup/publication/5276896

Knura, M., & Schiewe, J. (2022). Analysis of user behaviour while interpreting spatial patterns in point data sets. *KN - Journal of Cartography and Geographic Information*, *72*(3), 229–242. https://doi.org/10.1007/s42489-022-00111-9

Krug, S. (2014). *Don't make me think! 3. Auflage (3. Auflage)*. mitp Verlags GmbH & Co. KG.

Lewis, C., & Rieman, J. (1993). Task-centered user interface design. https://www.semanticscholar.org/paper/Task-centered-user-interface-design-Lewis-Rieman/27981facc2e94706c4fa22ab1756f09d44f8fe5f.

Lobo, M. J., Pietriga, E., & Appert, C. (2015). An evaluation of interactive map comparison techniques to cite this version: An evaluation of interactive map comparison techniques. *CHI 2015 - Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 3573–3582.

Marquez, J. O., Meirelles, P., & da Silva, T. S. (2021). Interactive web maps: Usability heuristics proposal. *Proceedings of the ICA*, *4*, 1–8. https://doi.org/10.5194/ica-proc-4-70-2021

Mayring, P., & Fenzl, T. (2019). Qualitative Inhaltsanalyse. In N. Baur, & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (pp. 633–648). Springer Fachmedien.

Aargauische Gebäudeversicherung. (o.J.). AGV Viewer—Gefährdungsübersicht. Gefährdungsübersicht. https://agv-ag.ch/static/gk/.

Popelka, S., Burian, J., & Beitlova, M. (2022). Swipe versus multiple view: A comprehensive analysis using eye-tracking to evaluate user interaction with web maps. *Cartography and Geographic Information Science*, *49*(3), 252–270. https://doi.org/10.1080/15230406.2021.2015721

QGIS Development Team. (2024). QGIS 3.28.08 [Computer software]. http://qgis.osgeo.org/.

Radoš, S., Splechtna, R., Matković, K., Đuras, M., Gröller, E., & Hauser, H. (2016). Towards quantitative visual analytics with structured brushing and linked statistics. *Computer Graphics Forum*, *35*(3), 251–260. https://doi.org/10.1111/cgf.12901

Raumplanungsverordnung (RPV). (2000). https://www.fedlex.admin.ch/filestore/fedlex.data.admin.ch/eli/cc/2000/310/20220701/de/pdf-a/fedlex-data-admin-ch-eli-cc-2000-310-20220701-de-pdf-a-1.pdf.

Roth, R. E., Çöltekin, A., Delazari, L., Filho, H. F., Griffin, A., Hall, A., Korpi, J., Lokka, I., Mendonça, A., Ooms, K., & Van Elzakker, C. P. J. M. (2017). User studies in cartography: Opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography*, *3*(sup1), 61–89. https://doi.org/10.1080/23729333.2017.1288534

Tufte, E. R. (1990). *Envisioning information. Eighth printing 2001.* (p. 126). Graphics Press.

Tufte, E. R. (2001). *The visual display of quantitative information (2nd ed.* p. 197*)*. Graphics Press LLC.

Unrau, R., & Kray, C. (2019). Usability evaluation for geographic information systems: A systematic literature review. *International Journal of Geographical Information Science*, *33*(4), 645–665. https://doi.org/10.1080/13658816.2018.1554813

Unrau, R., Kudekar, A., & Kray, C. (2022). Interaction pattern analysis for WebGIS usability evaluation. *Transactions in GIS*, *26*(8), 3374–3388. https://doi.org/10.1111/tgis.13007

Vanicek, T., & Popelka, S. (2023). The think-aloud method for evaluating the usability of a regional atlas. *ISPRS International Journal of Geo-Information*, *12*(3), 95. https://doi.org/10.3390/ijgi12030095

VERBI – Software. Consult. Sozialforschung. GmbH. (2024). MAXQDA | Die #1 software für qualitative & mixed-methods-Forschung [Computer software]. https://www.maxqda.com/de/.

Wetzel, D. & Amt für Raumentwicklung Kanton Schwyz. (2019). Kanton schwyz, planungshilfe 'der gestaltungsplan im kanton schwyz'. Kanton Schwyz, Volkswirtschaftsdepartement, Amt für Raumentwicklung. www.sz.ch/are/planungshilfen.