Journal of Urban Mobility 2 (2022) 100033

Contents lists available at ScienceDirect

Journal of Urban Mobility

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

Assessment of the usefulness of the accessibility instrument GOAT for the planning practice

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A R T I C L E I N F O

Keywords:
Accessibility
Active mobility
Pss

A B S T R A C T

Accessibility instruments could serve as powerful support in assisting planning practitioners. Though, accessibility instruments are usually not yet applied in practice. Past research has identified that besides institutional barriers in adopting accessibility, there is still a lack of useful instruments. It is suggested that tool developers engage closer with planning practice to better meet requirements from practice. The authors developed an interactive and web-based accessibility instrument called GOAT, focusing on active mobility in a co-creative environment with urban and transport planning practitioners. This manuscript aims to answer two research questions. Which planning questions exist for GOAT in the field of transport and urban planning? Is the accessibility instrument GOAT of useful support in the planning practice?

First, suitable planning questions were identified. The tools' utility and usability for the planning questions were self-assessed based on the experience in five applications workshops with 37 planning professionals in four German cities. The assessment was realized by analyzing workshop minutes and worksheets for the different planning questions. As a result, the usefulness was assessed for the planning questions and was summarized into four groups: Infrastructure Planning Walking, Infrastructure Planning Cycling, Location Planning, and Housing Development.

The assessment revealed that the tool helps answer common planning questions. In terms of usability, the tool could also be used by individuals unfamiliar with existing planning software after a half-day introduction. Meanwhile, practitioners requested further indicators and improvements in usability. Furthermore, stronger technical integration with existing systems should be envisaged. It is concluded that the involvement of planning practice was highly beneficial when developing and assessing the tool. Therefore, ongoing exchange and a long-term assessment of the tools' usefulness are suggested in the future.

1. Introduction

Active mobility is gaining escalating attention, while concepts such as the 15-min city have been presented as a vision for sustainable cities Cities (2020); Moreno, Allam, Chabaud, Gall, & Pratlong (2021); Pozoukidou & Chatziyiannaki (2021). Promoting active mobility is consistent, as no other mobility option combines benefits ranging from space efficiency, carbon neutrality, livability, and positive health impacts FGSV (2014); Kahlmeier et al. (2021); Koszowski et al. (2019).

There is consensus that active mobility, among others, requires an urban pattern characterized by relatively high density and diversity of opportunities, alongside appropriate transport infrastructure Buehler, Pucher, Gerike, & Götschi (2017); Kang (2015); Koszowski et al. (2019); Stead & Marshall (2001). In other terms, active mobility relies on high local accessibility Silva & Larsson (2019). The concept of accessibility, first defined by Hansen (1959), has been present in research for decades. However, little adoption in practice can be observed so far. Among other reasons, it is underlined that accessibility instruments are not yet meeting planning practice expectations (see Section 2.2).

Accessibility instruments are nowadays usually GIS-based tools to operationalize the concept of accessibility and therefore support planning processes. Accordingly, accessibility instruments are a subset of planning support systems (PSS) Papa, Silva, te Brömmelstroet, & Hull (2015). PSS promise to be appropriate tools for evidence-based and effective planning Geertman (2006); Geertman, Stillwell, & Top-

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https://doi.org/10.1016/j.urbmob.2022.100033
Received 7 November 2021; Received in revised form 17 April 2022; Accepted 16 September 2022

pen (2013); Klosterman (1997). However, there has been an imbalance between the supply and actual use of PSS since the beginning. This phenomenon, usually labeled as the *implementation gap* is discussed intensively in literature te Brömmelstroet (2010); Geertman (2006); Russo, Lanzilotti, Costabile, & Pettit (2017); Vonk, Geertman, & Schot (2006). It is argued that PSS lacks usefulness te Brömmelstroet, Curtis, Larsson, & Milakis (2016) or relevance for the planning practice.

To develop more useful instruments it is suggested to actively involve planning practitioners when developing PSS te Brömmelstroet (2010); Russo et al. (2017); Silva, Bertolini, te Brömmelstroet, Milakis, & Papa (2017). In this context, the authors developed Geo Open Accessibility Tool (GOAT) Pajares, Büttner, Jehle, Nichols, & Wulfhorst (2021a), an accessibility instrument focusing on modeling walking and cycling. It was developed in an applied research project in a co-creative and open environment with planning practitioners. The authors aim to help bridge the gap between research and practice in accessibility planning with the presented instrument. Early testing and application in practice heavily influenced the ongoing development process despite the development's initial direction. Previous publications on GOAT mainly focused on its technical background and the development process Pajares et al. (2021a); Pajares, Muñoz Nieto, Meng, & Wulfhorst (2021b). Therefore, this presented manuscript focuses on identifying its relevance for practice.

In particular, it should be studied if there are existing planning questions in the field of urban and transport planning in which the instrument is of useful support in practice. This study defines usefulness by the tool's utility and usability (see Section 4.3).The following research questions should be answered:

- RQ1: *Which planning questions exist for GOAT in the field of transport and urban planning?*
- RQ2: *Is the accessibility instrument GOAT of useful support in the planning practice?*

While there is a clear focus on the instrument GOAT, some results can also be generalized. In particular, the presented results should help other tool developers to identify further development needs. Furthermore, the experience during the co-creative development process can help other tool developers. For the planning practice, this contribution can reveal the potential for accessibility-based planning and the use of accessibility instruments.

First, the literature review in Section 2 should provide a better understanding of the current state-of-the-art in the field of PSS and accessibility instruments. Afterwards in Section 3 the GOAT project is presented to provide the technical background for the study. Subsequently, in Section 4, the methodology consisting of literature review and the co-creative application workshops will be introduced. After that, the results will be presented in Section 5. A discussion and conclusion will follow in Section6.

2. Literature review

2.1. Planning support systems in practice

Harris first proposed the definition of PSS as a "systematic process of sketch-planning" Harris (1989). Geertman (2006) defines PSS as:

> *"the PSS, can be understood as geoinformation-technology-based instruments that incorporate a suite of components (theories, data, information, knowledge, methods, tools) which collectively support all or some part of a unique professional planning task"*

The basic structure of PSS involves a database, model, and decision-making, which gives planners the ability to understand the inputs and outputs of the program Zhang, Hua, & Zhang (2016). In essence, a PSS is a tool for assisting urban planners with planning strategies, models, and visualizations Geertman, Allan, Pettit, & Stillwell (2017).

With the advancement of interfaces and algorithmic planning, many examples of PSS applications are now available. Early programs such as *Online What If? (OWI)* and *UrbanSim* have been used in practice for the last 20 years for their ability to model interrelationships between transportation and population, for instance Geertman et al. (2017); Pettit, Biermann, Pelizaroc, & Bakelmun (2020). Some different uses for PSS include, but are not limited to, disaster management Oki & Osaragi (2017); Osaragi & Noriaki (2017), transport management Meng, Allan, & Somenahalli (2017), and urban planning Leao, Huynh, Taylor, Pettit, & Perez (2017)). However, there is a distinction between systems that can present and visualize static data and ones where that can simulate scenarios and situations. Programs like *OWI, ENVISION*, and *CommunityViz* can be used for scenario planning by using static data and given specific parameters. On the other hand, programs like *UrbanSim* and *UrbanCanvas* are used as simulators and modeling tools for scenario planning Pettit et al. (2020). Depending on different situations, different uses and programs can be designed to assist with respective solutions.

Essential to the functionality and widespread use of PSS are its usefulness, usability, and the understanding of such programs Pettit et al. (2020), Russo et al. (2017). te Brömmelstroet & Bertolini (2010) argue that with the growing importance of integrated sustainable land-use and transport planning, the most significant barriers for application in practice are different tools, priorities, and functional tasks between urban and transport planning offices. Some PSS tools can bridge this gap. However, they can and have also stood as an "implementation bottleneck" to the process when tool development and practice are not well-linked te Brömmelstroet & Bertolini (2010). These bottlenecks are broken down into three groups by Jiang, Geertman, & Witte (2020). The first group comprises the number of unusable PSS tools published that lack usable attributes, transparency, or evidence of their efficacy when used. The second group comprises a lack of acceptance by planning offices due to misunderstanding of the tools or perceived risk of use to make major decisions. Finally, the third group includes learning ability and time to use PSS properly. te Brömmelstroet (2017) challenges PSS applications one step further and criticizes the research field for its focus on the user-friendliness of the instruments rather than their usefulness.

There are many proposed solutions to these issues, with some already implemented in the PSS field. In general, there are many proposals for including different stakeholders in the development of PSS that can streamline communication and create a useful feedback cycle Jiang et al. (2020); Vonk et al. (2006). Cooperation between PSS developers, particularly universities and planning offices, can also lead to better results in the application of PSS Geertman & Stillwell (2020); Luque-Martın & Pfeffer (2020). Another suggestion by Geertman & Stillwell (2020) is better education within the planning field on PSS and its benefits on evidence-based planning decisions at early stages in planners' careers. The primary differentiation in land-use and transport planning challenges PSS integration into the fields.

The review of existing PSS literature shows that instruments have been developed for at least three decades. Meanwhile, there is a high awareness of the lack of successful practice applications. Lacking usefulness is of particular importance for this manuscript. The useful support in concrete planning questions is seen as a minimum requirement for applying the developed tool GOAT in practice. Further factors such as institutional barriers are seen as equally important but will not be addressed in this manuscript.

2.2. Accessibility instruments and their potential

The earliest known definition of accessibility to the field was by Walter Hansen as "the potential of opportunities for interaction" Hansen (1959). Since then, there have been attempts at further studying, understanding, and measuring accessibility. The broad spectrum of accessibility was categorized by Geurs & van Wee (2004) into four components: transport, land-use, temporal and individual. These different dimensions of accessibility can be operationalized using suitable indicators commonly known as accessibility measures. Geurs & van Wee (2004) define four groups of accessibility measures: infrastructure-based, location-based, person-based and utility-based. Ideally, an accessibility measure should take all four accessibility components into account Geurs & van Wee (2004). Accessibility instruments can be seen as a subset of PSS. Papa et al. (2015) defined accessibility instruments as:

> *"Accessibility instruments (AIs) are a type of planning support system (PSS) designed to support integrated land-use transport analysis and planning through providing explicit knowledge on the accessibility of land uses by different modes of transport at various geographical scales."*

It is considered that they bear a large potential to provide planners with planning support when analyzing the complex relationship between transport and land-use te Brömmelstroet et al. (2016); te Brömmelstroet, Silva, & Bertolini (2014); Hull, Bertolini, & Silva (2012). More specifically, it is stated that accessibility instruments have the potential to be utilized as a shared language between disciplines, namely urban and transport planning Büttner, Kinigadner, Ji, Wright, & Wulfhorst (2018); te Brömmelstroet et al. (2016). A further advantage of accessibility instruments is that they can produce analyses on various spatial resolutions and all transport modes, including walking and cycling.

Besides the described benefits, accessibility instruments are not yet widely used in practice Bertolini & Silva (2019); Boisjoly & El-Geneidy (2017); te Brömmelstroet et al. (2016, 2014); Hull et al. (2012); Papa et al. (2015). Accordingly, accessibility instruments face an implementation gap between research and practice like other PSS. Following the literature, there are several reasons for this. Levine (2019) is stating that strict mobility metrics persist because transport engineering and urban/regional planning are explicitly instructed to use them. Furthermore, it is mentioned that accessibility is often conceptually misunderstood Levine (2019). There is evidence of a 'disconnect' between the tool developers and the users te Brömmelstroet et al. (2016). In addition, the availability of data is mentioned as a barrier to the broader application of accessibility instruments by tool developers Papa et al. (2015) and practitioners Boisjoly & El-Geneidy (2017); te Brömmelstroet et al. (2014). Also, practitioners report a lack of knowledge Boisjoly & El-Geneidy (2017) and resources in their institutions for the application of accessibility te Brömmelstroet et al. (2014). Past research has also shown that a powerful way to increase the usability and usefulness of tools being developed is the close involvement of potential users in the development process Bertolini & Silva (2019); te Brömmelstroet et al. (2016, 2014); Silva et al. (2017).

The research project (COST Action TU1002) showed that the feature that practitioners most desired was the real-time calculation of scenarios te Brömmelstroet (2017); te Brömmelstroet et al. (2014); Silva et al. (2017). Also, the potential of web technology to foster easier use and the involvement of more stakeholders are described to bear high potential Büttner et al. (2018); Venter (2016). An updated review of 26 accessibility instruments showed that instruments were developed significantly further, and many new tools were released. Following the fast development of WebGIS technology, a large share of web tools was observed among the studied instruments Pajares et al. (2021a). However, from the review Pajares et al. (2021a), no tool was found that combines the attributes: interactive scenario building for street network and land-use, open source development, focus on active mobility, and web-based. The development of GOAT was theoretically addressing the described gap and aimed to involve practitioners in the development process. Meanwhile, the concrete usefulness of the tool for practice remained unclear and, therefore, will be studied in this manuscript.

3. Accessibility instruments GOAT

In the following, a brief overview of the software GOAT is provided. Besides describing the core characteristics of the accessibility instrument, the technical architecture, data sets used, and core indicators are presented.

3.1. Overview GOAT project

The development of GOAT intends to help bridge the described gap between research and practice in accessibility. Currently, the instrument focuses on modeling accessibility for walking and cycling and local accessibility. In addition, it includes barrier-free and electric bike analyses. The GOAT project started with a Master's thesis Pajares (2017) and is currently taken forward as part of a dissertation project Pajares (2019); Pajares et al. (2021a). The software is developed open source GOAT-Community (2021a). GOAT has been used in applied research projects and was transferred to at least 27 municipalities. Out of them, there were five international applications: Bogotá (Colombia), San Pedro Garza García (Mexico), Matosinhos (Portugal), Boca Raton (Florida), and Atlanta (USA). The rest of the applications were in the German context.

GOAT tries to position between a simple web tool and a fully-featured desktop GIS in terms of functionality. By positioning in this niche, GOAT shares some similarities with existing accessibility instruments like CoAXs Stewart & Zegras (2016), TRACC Basemap Ltd (2022) or Conveyal Conveyal (2022). One core aim is that the application is usable by planning professionals not being familiar with GIS. Unlike most accessibility web tools, GOAT allows users to perform scenarios on the street network, points of interest, and buildings Pajares et al. (2021a). Based on the scenarios, changes in accessibility can be computed and visualized. Accessibility is interpreted using contour and gravity-based accessibility measures (see Section 3.3). A planning scenario can be drawn directly using the web interface or imported using the GeoJSON-format. Therefore, scenarios can be created outside of the application and re-import at a later moment. The development is characterized by an open and co-creative environment involving practitioners from the field of urban and transport planning.

In the following, the focus is particularly on three case studies in the Munich Region (Munich, Fürstenfeldbruck, Freising) and, to a smaller extent, on the case study in the city of Freiburg. The online version of the tool was launched in different years for the cities: Munich (2019), Fürstenfeldbruck (2020), Freising (2020), and Freiburg (2021). Meanwhile, the applied version of the tool and the used data sources varied between the different deployments. To the date of writing this manuscript, the tool was openly available online for the four mentioned cities. GOAT is provided open access on the project websites GOAT-Community (2021b); Plan4Better GmbH (2021). Besides the tool itself, the websites host step-by-step tutorials and documentation on the indicators, data, and software libraries being used.

3.2. Technical architecture

GOAT uses the classical server-client architecture of the web and is built solely using open source software (see Fig. 1). The backend is built around a PostgreSQL database, which is spatially enabled by the extension PostGIS. The backend analyses are realized using SQL, PLpgSQL, and Python. The database contains non-spatial and spatial data, as well analytical functions for the computation of the implemented accessibility measures and spatial operations (e.g. spatial intersection). Traveltime calculations are done using a custom implementation GOAT-Community (2020) of the pgRouting extension pgRouting Community (2022). The interaction with the database is handled by an API written in Python. The results of the analyses are communicated to the client using different non-spatial (JSON) and spatial formats (GeoJSON, Gebuf, Vector tiles). The client of the application is written in Javascript using the Vue.js framework and Openlayers as a map library.

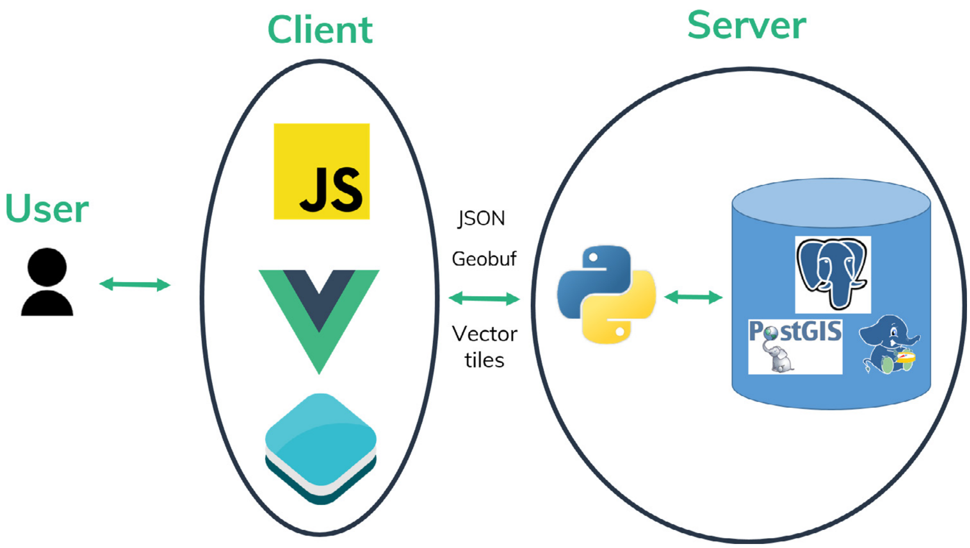

Fig. 1. Technical architecture GOAT.

Table 1
Data sets used.

Dataset	Purpose	Source
Points of Interest	Opportunities data set	OSM, own collection in OSM, Provided by Municipalities
Land-use	Population disaggregation, Visualization	OSM, Landesamt für Digitalisierung, Breitband und Vermessung Bayern, Urban Atlas - European Environment Agency (EEA)
Buildings	Population disaggregation	OSM, Landesamt für Digitalisierung, Breitband und Vermessung Bayern, Provided by Municipalities
Population grid	Population	ZENSUS 2011
Administrative areas with population	Population	Provided by Municipalities, Bundesamt für Kartographie und Geodäsie, Landesverkehrsmodell Bayern
Street imagery	Visualization and Mapping Mode	Mapillary, own collection in Mapillary
Street network	Routing	OSM, own collection in OSM
Elevation	Routing	European Environment Agency (EEA)
Accidents pedestrians and cyclists	Visualization	Statistische Ämter des Bundes und der Länder
Data on environmental quality	Visualization	Bayerisches Landesamt für Umwelt, FreiGIS
Bike counting data	Visualization	Geodatenservice München
Modal split	Visualization	Mobilität in Deutschland (MiD)
Basemaps	Visualization	OpenStreetMap, Mapbox, Bing

The tool was equipped with diverse (spatial) data for the different case studies and installed on a cloud server using Kubernetes. Data is seeded into the application using different data preparation, disaggregation, and fusion steps. Depending on the region deployed, there are used different data sets. Meanwhile, GOAT can theoretically work solely with OSM and population data sets. However, other (open) data sources are used to yield a higher data quality and completeness. The most important data sets used are summarized in Table 1.

3.3. Implemented indicators

The instrument is modeling and visualizing accessibility through an interactive web map. It interprets accessibility using contour and gravity-based accessibility measures from the group of location-based measures Geurs & van Wee (2004). Furthermore, different spatial data such as data on traffic accidents, street imagery, land-use, and modal split can be visualized and styled on the map. Fig. 2 visualizes the core indicators of the application.

As contour measures, two forms of isochrones are implemented. Single-isochrones are catchment areas from one starting location. The isochrone polygon shape intersects with the opportunity data set and population data to calculate cumulative opportunities. Results are visualized on the web map and a table. The second isochrone type are multi-isochrones. For multi-isochrones, the user either defines an area of interest by drawing a study area polygon or picking one or more city districts. Based on the user selection points of interest categories are considered. The coordinates of points of interest are taken as starting points. The individual isochrones are unioned and intersected with the population data. As a result the multi-isochrones are shown on the map and the share of the served population located within the study area of choice is listed in a table in relative and absolute numbers. Both isochrone types can be calculated with all supported routing modes and reflect all forms of scenario building (network, points of interest, and buildings). The user can adjust travel speeds for the different routing modes.

A third indicator is described as a connectivity heatmap. In the authors ’ opinion, the indicator can be positioned between infrastructure-based and contour-based accessibility measures. The heatmap is computed using a hexagonal grid with an approximate edge length of 150 m per cell for walking mode (5 km/h). Three isochrones (5, 10, and 15 min) are pre-computed using the centroid as a starting point for each grid cell. The size of all three isochrones is summarized per cell and compared with all other cells using statistical quintiles. The grids are colored from high (green) to low connectivity (red). Changes in the street network are reflected by recomputing parts of the heatmap and updating the statistical classification. As a gravity-based accessibility measure, an additional heatmap is implemented. The heatmap is created based on pre-computed traveltimes. Traveltimes are computed for

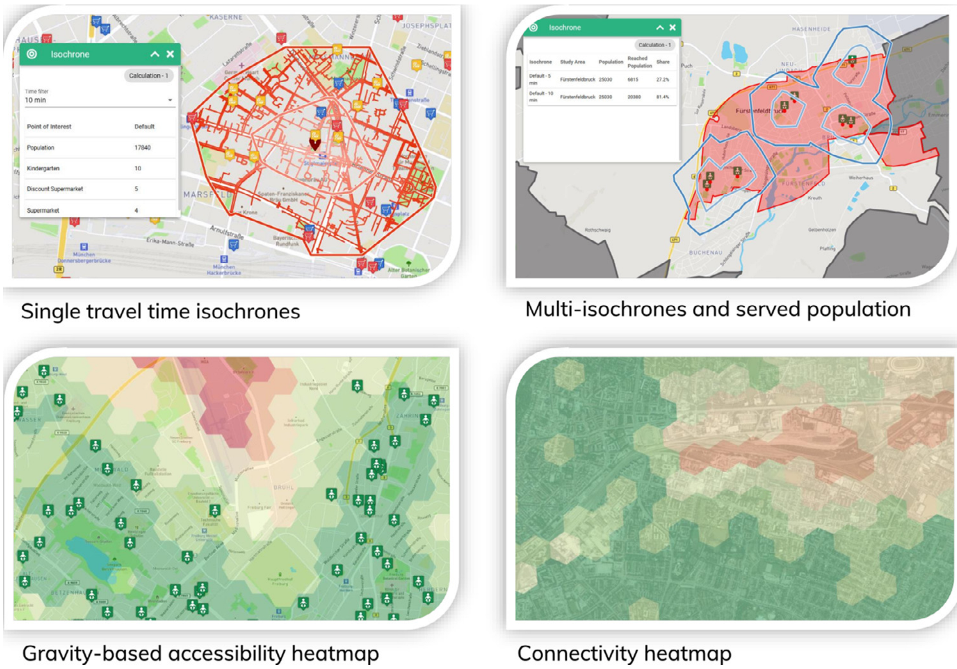

Fig. 2. Core indicators GOAT.

walking (5 km/h) for each grid to all points of interest within a 20-min cutoff. Accessibility values are computed per grid using the widely applied formula:

$A_i = \sum_j O_j * f(t_{ij})$

As impedance function a modified gaussian function is implemented:

$f(t_{ij}) = e^{t_{ij}^2/\beta}$

The heatmap is dynamically created for the selected point of interest categories based on the pre-computed traveltimes. Furthermore, the user can customize the heatmap by giving each point of interest category a weight and choosing an appropriate sensitivity value. Therefore, individualized composite indicators can be built by the user. Currently, the gravity-based heatmap only reflects scenarios on points of interest.

4. Methodology

The following chapters provide an overview of the methods used for the study. It focuses on providing an overview of the user involvement during the development, the workshop protocol, and the method for assessing the instruments' usefulness.

4.1. Overview user involvement

The input from practitioners influenced the development and application of the instrument. The open development and provision of the tool facilitated the involvement of diverse groups. In particular, three groups were involved: planning practice, research and developer community and students (see Fig. 3). The process brought up ideas on new features proposed new use cases and helped understand user needs. A particular focus was given to exchange with the planning practice. Past research has shown (see Sections 2.1 and 2.2) that the involvement of planning practice can help in developing more useful PSS. Involvement was realized through early testing workshops and later in application workshops (see Section 4.2). Besides practitioners' direct use of the tool, results or the tool itself were shown in presentations to planners and decision-makers. Alongside this, more informal exchange was carried out in personal meetings.

With ongoing development, the exchange with the research and developer community intensified. Besides early testing with German researchers, two workshops with international researchers were carried out. Next to scientific publication, the current development progress was continuously communicated in a blog and social media. Furthermore, feedback on users' experience was obtained via Social Media, E-Mail, and a chat group.

The involvement of students in different teaching formats was the third pillar of the co-creative development of GOAT. Direct contributions were realized in several students' theses, in which new features were developed, or the application was transferred to a new study context. The development was usually accompanied by internal or external testing of the tool. Furthermore, students used the demo version of GOAT in Munich in seminars and lectures to perform accessibility analysis or visualize spatial data. Due to the importance of (spatial) data for the development, students were also involved in four Mapathons, which aimed to collect data on street networks, buildings, and points of interest in OpenStreetMap (OSM). As part of this activity, a prototypical feature was developed in GOAT, which showed gaps in the OSM data set and provided a more structured crowdsourced mapping process. Despite the richness of the different involvement formats, the exchange happened largely unstructured and, in many cases, spontaneous. Therefore, in the following, a particular focus is given on the experience obtained in the application workshops.

4.2. Application workshops

For the early development phase, practitioners from the field of transport and land-use planning from the municipality of Fürstenfeldbruck were involved Pajares et al. (2021a). This first series of workshops primarily aimed to receive feedback on principle requirements of users and test different pre-release versions of the tool. Meanwhile, the main aim of the application workshops was to work on real-world planning questions using the tool. It was aimed to achieve an experience when using the accessibility instrument, which is close to the work reality of the practitioners. However, due to the unfamiliarity of the majority of the practitioners with accessibility measures and with using GOAT, the workshops also had characteristics of method and software training.

The workshops were organized in the citys' administrations of Fürstenfeldbruck, Freising, and Munich. An additional application workshop was organized with researchers from transport and land-use planning in Munich. The workshops took place in 2020. Due to the COVID-

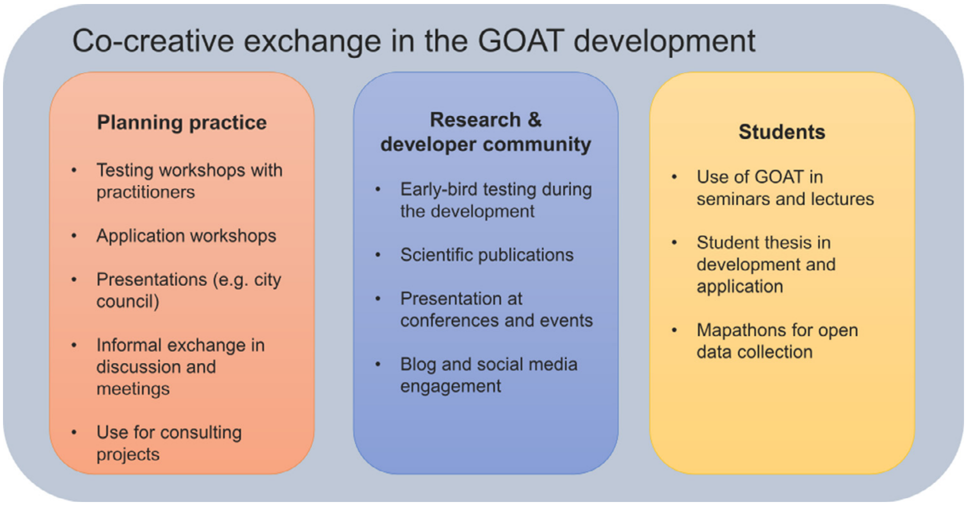

Fig. 3. Main user groups involved in the development of GOAT.

Fig. 4. Application workshop in Freising and Fürstenfeldbruck.

19 restrictions, two application workshops were organized remotely via teleconferencing. Overall, 37 persons attended the five application workshops, and each took approximately three hours. The practitioners were almost entirely coming from urban and transport planning (see Fig. 4). Approximately half of the practitioners focuses on urban and the other half on transport planning. From the authors' observations, the majority of practitioners though had a good understanding of the interrelation of both disciplines. One of the workshops was also joined by a politician from the city council.

The workshop design was inspired by the workshops conducted in the course of the COST Action TU1002 te Brömmelstroet (2017); te Brömmelstroet et al. (2014); Silva et al. (2017). However, the detailed workshop procedure was designed independently from existing protocols. The core difference between the workshops conducted in the COST Action TU1002 was that the practitioners were operating the accessibility instruments themselves, and the tool developers only intervened for support. Before the workshops, the participants were asked to share relevant planning questions in their respective municipalities. Also, it was communicated which functionalities the tool has by sending videos, links, and learning material about the software via E-Mail. However, most practitioners were not familiar with the software before the workshop to the authors' knowledge. An exception were planners from the city of Fürstenfeldbruck, who have used GOAT in the test cycles. The workshops used the worksheet presented in Fig. 5 and followed the protocol described in Table 2.

The research team documented observations, feedback, and discussion for each workshop. Although the focus during the workshops was on assessing the tool's usefulness, requests for new features or adaptions and bugs were documented. After the workshops, the participants had the chance to provide further feedback via E-Mail or telephone. An additional application workshop was realized in the city of Freiburg in summer 2021 as a videoconference with five participants. The workshop took two hours and was not supported by the working sheets. It was characterized by a short testing round and a discussion of the tool's functionality.

4.3. Usefulness assessment

Self-assessing the usefulness of an instrument under development is a complex challenge. The diversity of possible planning questions and the limited time the practitioners used the tool shows that there can be no definite answer. Therefore, the assessment should be seen as preliminary. The authors followed the assessment framework visualized in Fig. 6. The assessment started with identifying suitable planning questions for GOAT. In the following, the practitioners worked on the planning questions as described in Section 4.2. Because of the high number of possible planning questions, the authors grouped them into thematic fields (see Section 5).

In the following, the usefulness was assessed for each thematic cluster by showing the used tool features and qualitatively discussing the usefulness based on the users' feedback. Following the literature review (see Section 2), past research has identified that it should be differentiated between the usability and usefulness of a PSS. In the context of this study, usability is seen as part of usefulness. Grudin (1992) and Nielsen (1994) suggest splitting the usefulness of software into utility and usability. Both aspects together define whether the software is useful or not. More specifically, utility is defined by Nielsen (1994) as:

> *"utility is the question whether the functionality of the systems in principle can do what is needed"*

For the assessment of GOAT, the authors particularly examine if the instrument provides the planners with information relevant to them

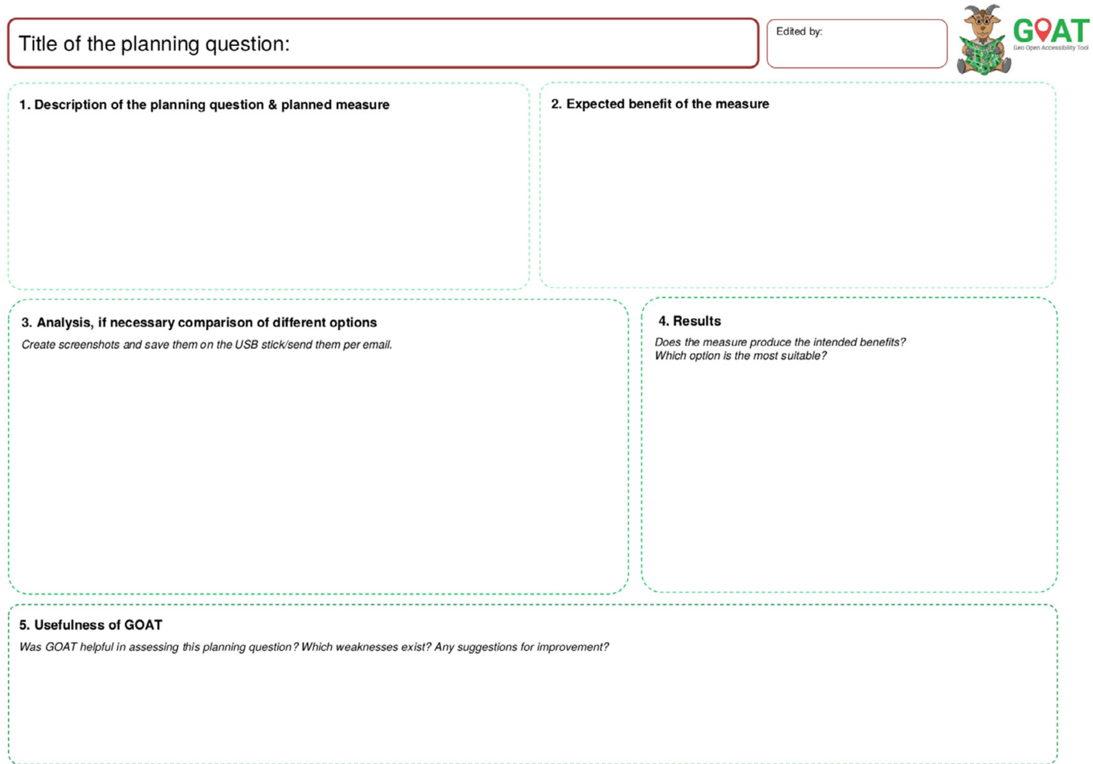

Fig. 5. Worksheet planning workshops.

Table 2
Agenda planning workshops.

Agenda item	Explanation
Welcome and a round of introduction (15 min)	Each person presented himself and described his core work-related responsibilities and interests. The aim was to build a relationship and understand the participants' motivation and interests.
Presentation of GOAT (30 min)	Two persons of the research team presented GOAT. The main aim was to show the core functionalities of the tool. Meanwhile, the practitioners could ask questions or describe planning questions they face in their daily work. The previously collected planning questions (via E-Mail) were expanded or complemented at the end. The introduction should provide enough information to get started on working with the tool.
Group work planning on planning questions (45 min)	A group of two to three practitioners for each planning question was formed. Each group should work on at least one concrete planning question using the tool on the territory of their municipality. They received a step-by-step guide showing the use of the tool. Meanwhile, they were supported by the research team in case of questions. The results of the analyses were documented on the worksheets and with screenshots. Furthermore, the results were within each group. The goal was that the practitioners obtain hands-on experience using the tool and assess its suitability for the respective planning question.
Coffee break (15 min)	During the scheduled break, the practitioners could take a rest. Furthermore, the research team had the chance to openly discuss their first experiences using the tool and possible ideas with the practitioners. Furthermore, the break should help to strengthen the relationship with the practitioners through the open exchange.
Group work planning on planning questions (45 min)	The participants continued working in the same group as before the break.
Presentation of the results per group/planning questions (15 min)	For each group, one practitioner presented the results of the analyses by explaining the content of the filled worksheet and by showing the analyses directly via the tool or with screenshots. The goal was to present all other attendees with the studied planning question and share their experience in using GOAT. Both the research team and the other practitioners could ask questions and discuss.
Open feedback and discussion (15 min)	Finally, the practitioners could openly express their feedback on the tool and propose possible enhancements. The goal was to give the practitioners the chance to provide unstructured feedback on the tool's usefulness and collect feature requests for upcoming versions of GOAT.

when answering a particular planning question. This also includes the appropriateness of specific indicators and the power to communicate the results to other stakeholders (e.g., politicians). Past research (see Section 2.2) identified that the tool interactivity, particularly the ability for real-time scenario building, is important. Therefore, the assessment of utility will set this as one important criterion.

However, high utility alone would not necessarily result in a useful tool. Instead, high usability is very relevant for the assessment of PSS. More specifically, GOAT is assessed whether it is usable for individuals with no or limited knowledge of GIS. In general, usability can be 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"* ISO (2018).

Of particular importance was to assess if the tool was easy and intuitive to use for the different planning questions. Furthermore, there was attention to users' emotional experience when operating GOAT. Despite

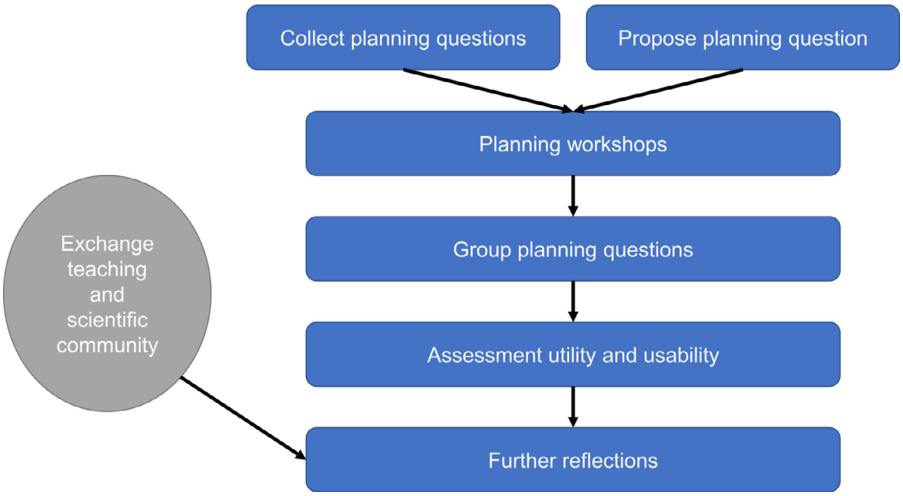

Fig. 6. Framework assessment usefulness.

Table 3
Overview planning questions.

Use case group	Planning questions
Infrastructure Planning Walking	Where is a barrier for pedestrians concerning the street network connectivity? How does a new pedestrian bridge influence connectivity? What effect brings the temporary closure of a path on accessibility? How does accessibility for a person in a wheelchair change by the barrier-free upgrade of an underpass or bridge?
Infrastructure Planning Cycling	How does a new cycle bridge influence local accessibility? What effect has a new cycleway on accessibility? How do different cycleway attributes influence accessibility? What are suitable locations for bicycle parking infrastructure? How comfortable is it to cycle on a certain cycleway?
Location Planning	How fair is the distribution of different amenities in a municipality? Which share of the population has access to a specific amenity? Moreover, which areas are underserved? Where is a suitable location for placing a new amenity (e.g., supermarket, kindergarten)? What effect brings the closure of a specific amenity (e.g., pharmacy) to local accessibility? Is the population served sufficiently with public transport stops? Where is the potential for a new public transport stop or a mobility hub?
Housing Development	Where is the potential for urban densification? What are the effects of densification on local accessibility? Is the layout of the path network appropriate in a new development area to provide high local accessibility? How good is the population supplied in a new development area with different amenities? How are population density and local accessibility balanced for a specific amenity?

the broader involvement of stakeholders, it is worth mentioning that the assessment focused on the feedback from planners during the workshops. A challenge for this study is to extract and classify distinct conclusions from the recorded results. Overall the participation process yielded only minimal quantitative results. Therefore the assessment is mainly based on the qualitative description of the user feedback and user statements. Furthermore, the authors' complemented the assessment with their own observations. In the following result section, if statements are based on authors' observations, they are particularly labeled to provide transparency.

5. Results

The co-creative process resulted in identifying a wide range of possible planning questions. It was decided to generalize the planning question and group them into four categories: Infrastructure Planning Walking, Infrastructure Planning Cycling, Location Planning, and Housing Development. The most widely discussed planning questions in the context of the workshops are presented in Table 3.

For each group, exemplary analyses from GOAT, done during the planning workshops, are presented. They can be regarded as the most frequently performed analyses in the respective group. Section 5.1 bundles results for planning Walking Infrastructure, Section 5.2 for Cycling Infrastructure, Section 5.3 for Location Planning, and Section 5.4 for Housing Development. It has to be mentioned that the analyses for the different use cases can overlap due to the high interrelation of the studied questions.

5.1. Infrastructure planning walking

5.1.1. Provided features and analyses

Different indicators serve as benchmarks for street connectivity and accessibility of local amenities for planning walking infrastructure. The connectivity heatmap in GOAT allows the user to understand the degree of street network connectivity in the study area. Using the heatmaps (see Fig. 7), the practitioners understood the street network connectivity. In the studied municipalities, especially rivers and rail tracks were identified as significant barriers. Users performed scenarios on the street network by adding, modifying, and deleting network elements. Accordingly, common infrastructural measures such as constructing a new footbridge, a temporary network closure, or a sidewalk extension were modeled. As shown in Fig. 7, connectivity is significantly improved with the proposed bridge over the river. The areas that benefited the most are in the direct surroundings of the bridge.

Also, by using single and multi-isochrones, changes in accessibility were computed and visualized. As shown in Fig. 8, a new pedestrian bridge over a river increases the catchment area. As a result, significantly more population and amenities can be reached from the respec-

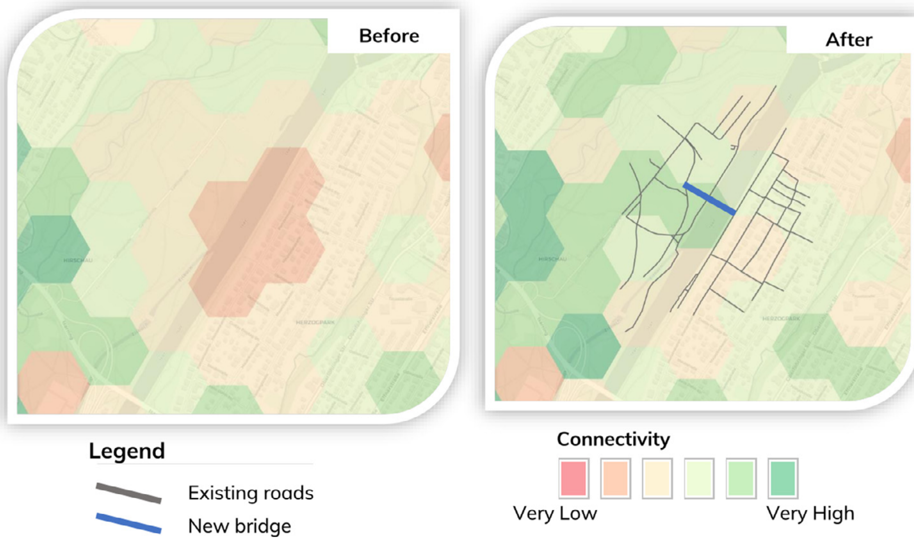

Fig. 7. Bridge scenario and changes in connectivity.

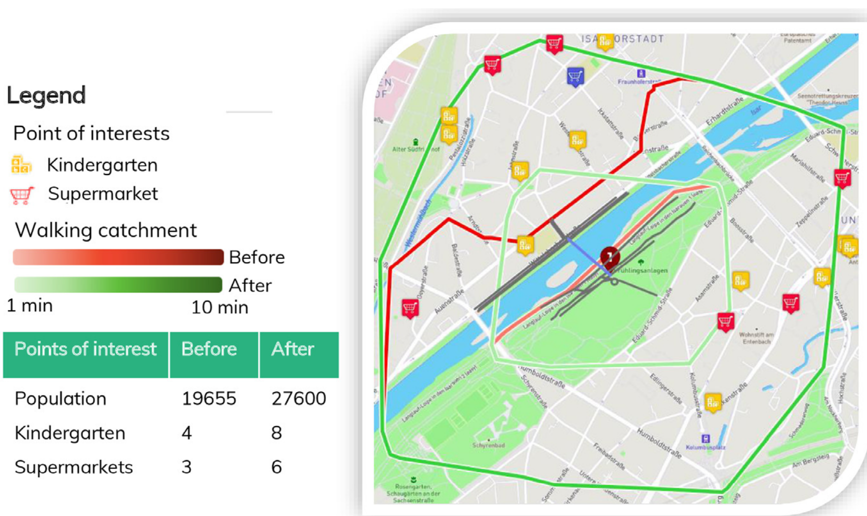

Fig. 8. Scenario new pedestrian bridge over a river.

tive location. The same calculations were done for the barrier-free mode. The effects of providing additional barrier-free crossings over a river are visualized in Fig. 9. Depending on the data available in the city, users visualized street illumination, noise levels, street crossings, surface, and more.

5.1.2. *Assessment of usability and utility*

In general, the practitioners reported that analysis using isochrones was straightforward. The local knowledge of the planners confirmed barriers in the street network identified by GOAT. They were surprised by the ease of changing the network and the performance of the scenario building. Users valued that the computed isochrones can easily intersect with diverse spatial data such as population numbers and points of interest. The isochrones were also commonly understood by participants unaware of the accessibility concept. Several planners mentioned that the produced maps using isochrones could be powerful when presenting results to politicians. While the connectivity heatmap offers an area-wide benchmark, the users had more difficulties understanding the indicator. Also, computing scenarios using the connectivity heatmap take significantly longer than single isochrones. The provided documentation of the indicator helped to improve understanding and required more time. In some cases, the network modification produced unexpected results. Reasons for this were problems with data accuracy and sporadic bugs in the relatively complex feature. In the workshops, it was observed that new users had difficulties performing network scenarios for the first time. In the workshops, not all users managed to design a scenario themselves but required assistance from one of their colleagues or the research team. While most users were interested in the travel time-based isochrones, others also used additional layers such as noise levels. Some users mentioned the need to consider walkability-related factors (e.g., sidewalk width, noise levels) to provide a complete picture. As sometimes new paths or bridges showed only marginal changes in accessibility, one planner mentioned that: *"Accessibility analyses cannot really show the effects of this measure"*. Users also requested to provide classical origin-destination-routing to supplement the isochrone calculation.

5.2. *Infrastructure planning cycling*

5.2.1. *Provided features and analyses*

Due to the fast-rising attention to cycling in the studied municipalities, several practitioners were particularly interested in using GOAT for analyzing the cycling infrastructure. There is no heatmap yet implemented for cycling infrastructure planning. Therefore only isochrones and multi-isochrones were used for cycling. However, similar to the network changes for walking, the cycling network can be changed. In addition, the road surface can be changed in a scenario. A common scenario

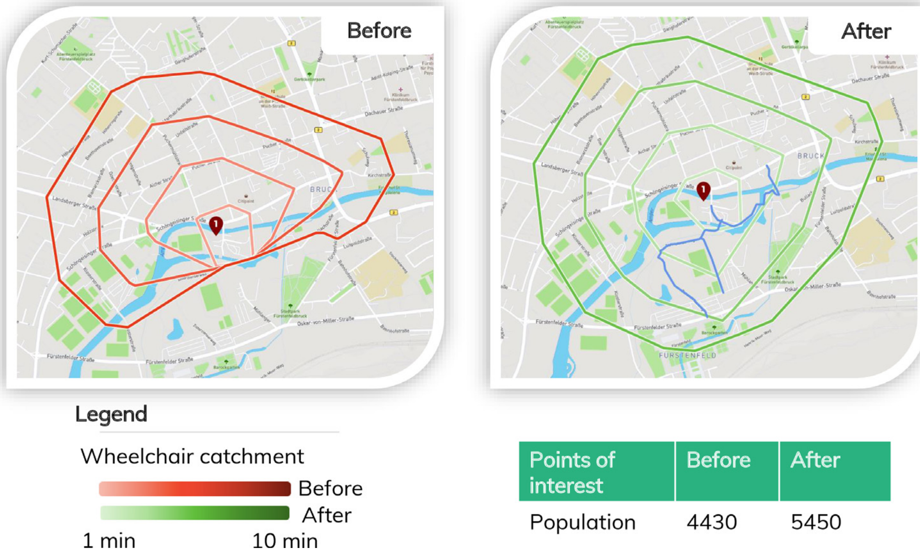

Fig. 9. Scenario new barrier-free crossing.

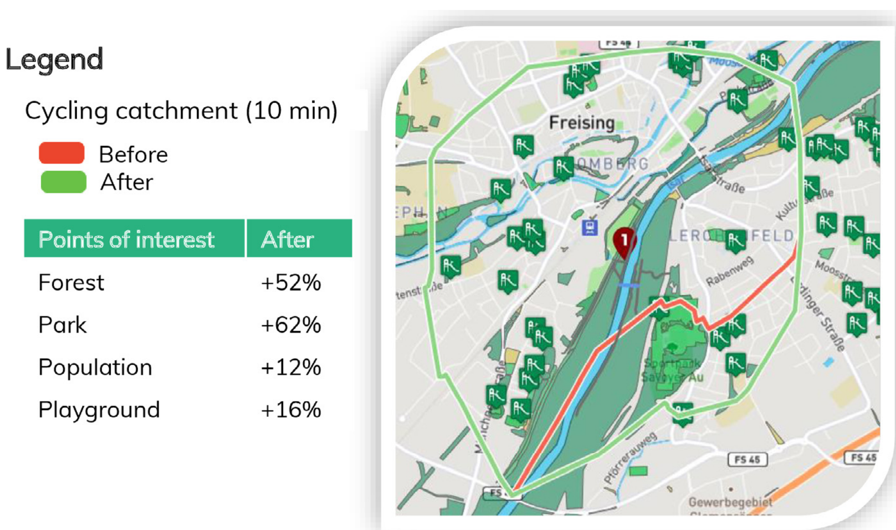

Fig. 10. Analyses and data visualization for planning cycling infrastructure.

in all three municipalities was to analyze the accessibility effects of a new cycling bridge over the local river as shown in Fig. 10.

Other layers were also used for analysis. For instance, street imagery from Mapillary was used to inspect the cycleway quality and get a better understanding of the study area (see Fig. 11). In the case of Munich, the data on cycleway quality from the local NGO Munichways Munichways (2021) was frequently viewed. Furthermore, data on cycling accidents were utilized to identify hotspots and particular needs for action.

5.2.2. *Assessment of usability and utility*

The user feedback revealed that, in general, computed travel times were perceived as realistic. It was highly valued that the travel time analyses included slope and surface type factors. Also, the ability to adjust cycling speeds and choose between different cycling profiles (standard or electric) was appreciated. However, it was also requested that the impedances (e.g., slopes, surfaces type) on the road network should be made more transparent. One user mentioned: *"I would like to have more transparency on the impedances applied for the cycling network"*. Others users mentioned that this would increase trust in the calculations.

Users also wished to model travel time differences between different cycleway types, for instance, between a narrow cycleway and a cycling highway. As this is not yet implemented, modeling the effect of high-quality cycling infrastructure could not be done so far. Due to the unavailability of appropriate data, travel time losses are only considered at major intersections with traffic lights. An average time loss of 30 s is applied for crossing the intersection in every direction. This was perceived as a limitation by some users. It was wished to model the effects of changes in the design of intersections or the traffic signal plan. Generally, it was claimed that the presented accessibility analyses could not model the effects of all discussed measures (e.g., traffic signal prioritization). The same was valid for walking analyses, but more planning questions related to cycling were not answered in the workshops. Meanwhile, as for walking analyses, the importance of additional comfort criteria (e.g., number of other cyclists) was raised.

As the catchment areas for cycling are much larger than for walking, the performance of the isochrone calculation is significantly slower. Especially for the computation of multi-isochrones uncomfortable long computing times of several minutes can affect the user experience. Furthermore, users missed a comparison of traveltimes between bicycles and cars. Users appreciated the additional data, particularly the street view imagery from Mapillary as GoogleStreetView imagery in Germany is usually either unavailable or out of date.

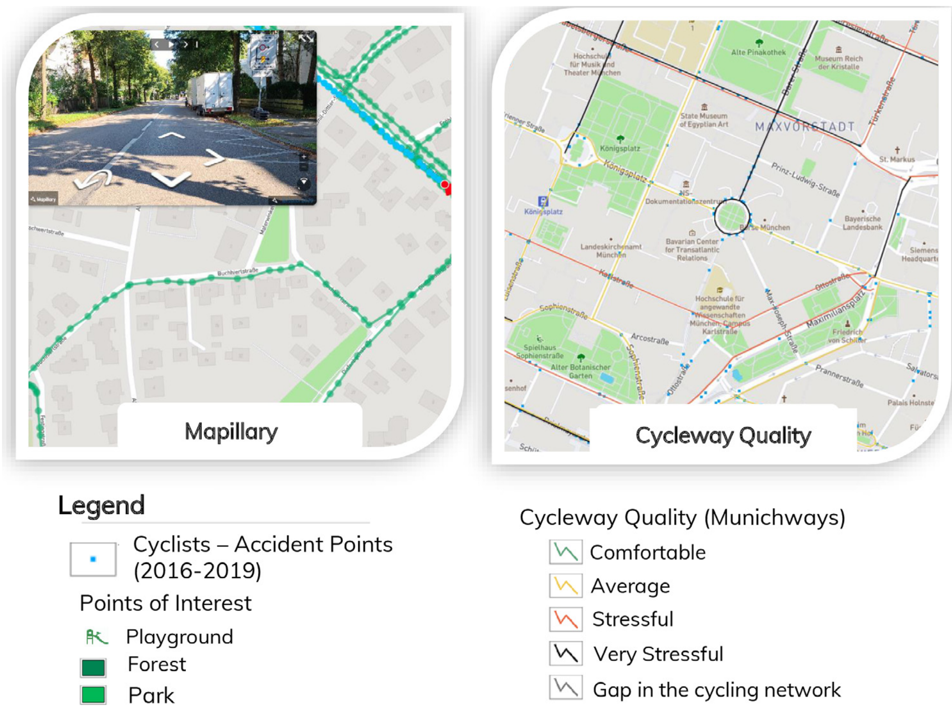

Fig. 11. Analyses and data visualization for planning cycling infrastructure.

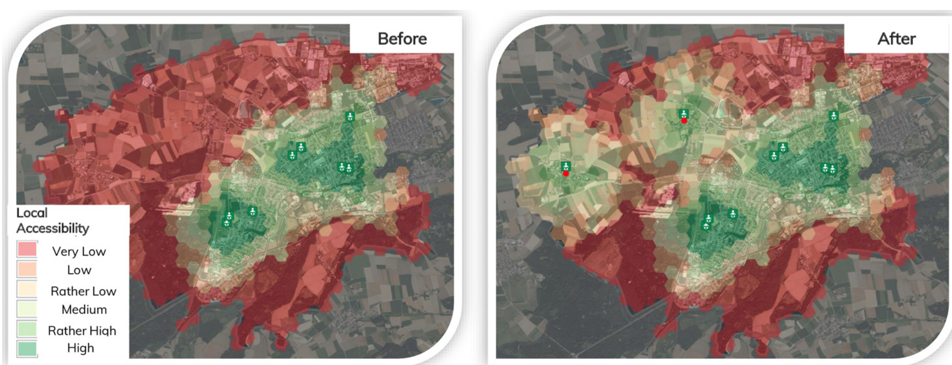

Fig. 12. Location planning social facilities - nurseries in Fürstenfeldbruck.

5.3. Location planning

5.3.1. Provided features and analyses

GOAT was used for location planning, such as finding a suitable place for a new service or evaluating the served population with a particular amenity. With the gravity-based accessibility heatmap, the users evaluated the accessibility to a specific amenity for the city's territory. Therefore, underserved or not served areas were identified. By drawing scenarios, like adding a new bike-sharing station, the change in accessibility was modeled by the users. It was tested to add, modify or delete points of interest. Therefore, the accessibility effects of new and closed points of interest were evaluated. Fig. 12 shows the accessibility effects of two new nurseries in the City of Fürstenfeldbruck.

The population heatmap was also used to assess the balance of accessibility levels and population density (see Fig. 13). With the population density and local accessibility heatmap, accessibility was compared with the population density at the respective grid cell. Areas with a high population but poor accessibility were highlighted. As shown in Fig. 14, the areas with the proposed new nurseries indicate a modest density surplus. With the proposed two new nurseries, the affected areas are balanced or have a modest accessibility surplus in the scenario.

5.3.2. Assessment of usability and utility

For location planning, mainly the described heatmaps and multi-isochrones were utilized by the practitioners. Generally, they classified the local accessibility heatmap as a powerful indicator to highlight the distribution of a certain point of interest. However, one user also mentioned that more quantitative output would be desired: *"Difficult, to only work with visuals, more quantitative results would be helpful"*.

Although the sensitivity parameters of the gravity-based accessibility measure could be adjusted, the users did not do this. Instead, the default parameters were utilized. From the authors' observation, the users were already overwhelmed by many functionalities and therefore showed little interest in increasing complexity by calibrating the sensitivities. The multi-isochrones were seen as a powerful indicator to show which population share is served by a particular amenity. The scenario development for the points of interest was more straightforward than for the ways or buildings. Also, users liked how fast the heatmap reflected the scenarios. The combination of population densities and accessibility levels was seen as a good approach to balancing supply and demand. However, concerns were raised if it is sufficient to include population numbers solely. More specifically, data on the number of jobs or students at education facilities was considered essential to quantify the demand

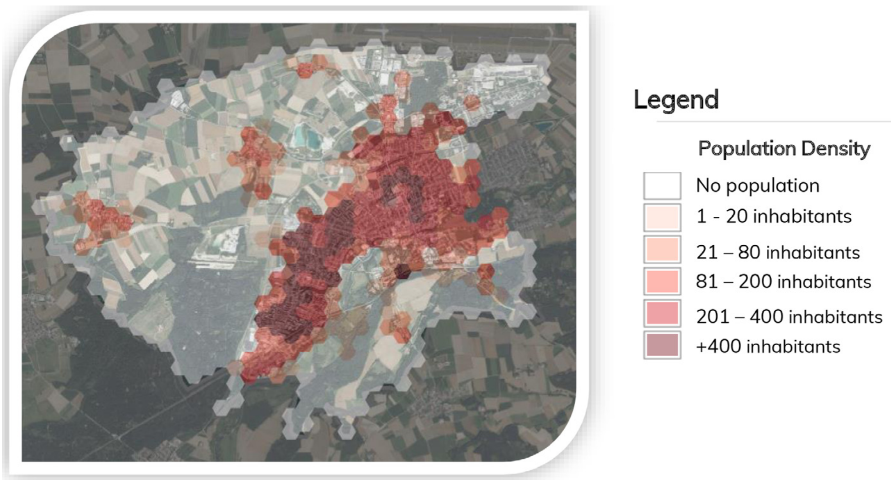

Fig. 13. Population density heatmap, Fürstenfeldbruck.

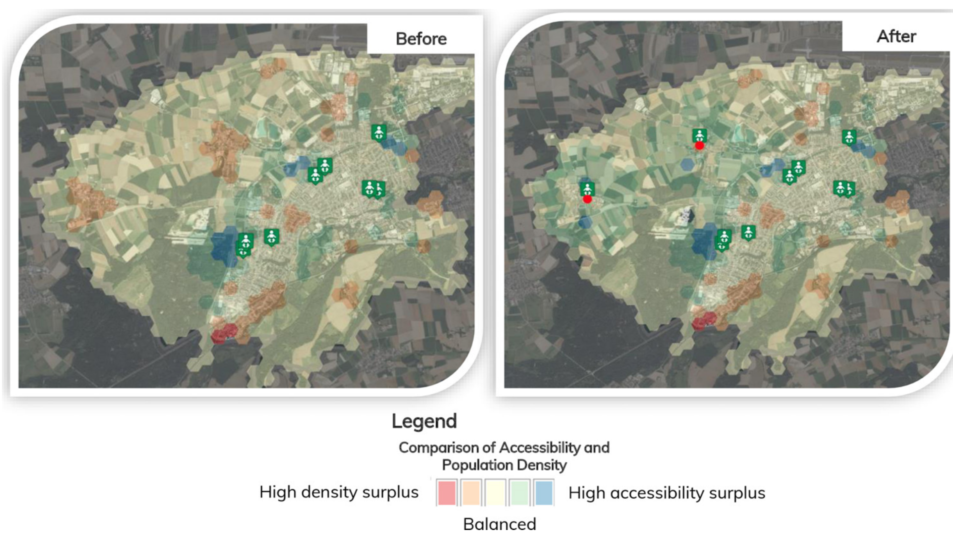

Fig. 14. Comparison of accessibility and population density heatmap, Fürstenfeldbruck.

for some points of interest (e.g., supermarkets, public transport stops). Generally, population numbers are static and reflect people's location at night or early morning. Spatio-temporal changes in people during the day are not available. Also, due to the unavailability of data on opening hours for all points of interest, temporal changes in accessibility could not be modeled. The authors perceived modeling the temporal changes of accessibility due to varying opening hours at the beginning of the study as particularly important. However, this was barely requested by the involved practitioners.

Users generally confirmed that the accessibility levels for the different amenities match their personal experience. However, they also requested more tailor-fitted indicators to assess the demand for a particular service and the quality of an amenity. Especially for public transport stops, it was requested to incorporate factors such as service frequencies to quantify the attractiveness of the service better. Additional sociodemographic data on age, family status, and income were requested to understand better the needs and demands for a particular point of interest. At the same time, users mentioned that this raises the complexity of the analyses.

5.4. Housing development

5.4.1. Provided features and analyses

The distribution of the urban population is constantly changing. Common interventions in the urban environment are the construction and demolition of buildings. To model changes in the population distribution in GOAT, houses were drawn and imported via the interactive web map. With an adjustable average gross floor area per resident, the population is estimated per building. Furthermore, it is possible to delete existing buildings. With the scenarios, the users aimed to model changing needs of accessibility by using isochrones, multi-isochrones, and heatmaps. As shown in Fig. 15, buildings were uploaded as GeoJSON from a building development plan in Munich. In addition, the planned street network was added to the scenario.

Fig. 16 shows the accessibility to kindergartens in the new development area. There are three existing kindergartens accessible in 8 min walking time. For better accessibility of the new residents in the scenario, a new kindergarten is proposed at the east of the new development area. Accordingly, around 20.9% of the population has access in 4 min, and 100% of the people in 8 min walking. The example shows that GOAT can be used for planning urban development.

5.4.2. Assessment of usability and utility

The practitioners liked that an entire neighborhood could be modeled as a scenario. This was considered useful as new development areas could be evaluated concerning their local accessibility to diverse destinations. Furthermore, the feature was regarded as suitable for identifying places with high accessibility and, therefore, potential for urban densification. The implemented accessibility measures, especially the

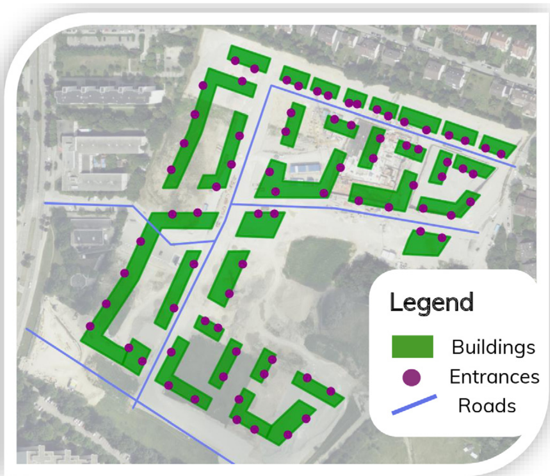

Fig. 15. Scenario with buildings uploaded from a building development plan and new road infrastructure.

multi-isochrones, were used to quantify the share of residents having access.

In terms of usability, drawing new buildings were generally perceived as intuitive. Nevertheless, some users mentioned that drawing individual buildings and building entrances is too time-consuming. It was mentioned that a coarser resolution of the population would also be sufficient for many use cases. It was welcomed that buildings can be uploaded in the GeoJSON format. At the same time, the format was not frequently used by all participants. One user mentioned that it would be necessary to allow uploading data in the shapefile format. Despite the option to export and later import drawn scenarios, it was raised that it would be beneficial to save developed scenarios in the tool. While being true also for ways and points of interest scenario, users mentioned this would be particularly important for buildings as drawing them takes more time. Working with the practitioners also revealed that additional, more granular accessibility indicators on the building level could provide valuable insights. One example could be providing information on travel times to selected points of interest when clicking on a building.

Table 4
User feedback - general .

Positive feedback	Negative feedback
"GOAT has developed very positively, many good new features."	"Sceptic about making the tool accessible to the public, due to sensitive data and data accuracy."
"Very impressive tool."	"Walking and cycling are great, but multimodal analyzes are needed for mobility concepts."
"Very exciting project."	
"Great what you can do with Open Data."	
"Scientific background is a big plus."	

Table 5
User feedback - usability.

Positive feedback	Negative feedback
"Very easy to use (good user interface)."	"User interface is not user-friendly and intuitive enough."
"Easy to understand after a short training period."	"Familiarization with the software takes too long."
"Simple user interface."	"Too complex to involve citizens."
"Quick and easy comparison of different scenarios."	"Overwhelmed by too many functions."
"The results are easy to understand and striking."	"Functions are not always self-explanatory."
"Intuitive to use."	"Terminology not comprehensive."
"Analyses are easily possible without extensive GIS knowledge."	"Too complicated, I prefer to hire a GIS professional."
"Time- and cost-efficient tool."	
"Interactivity of the tool is good."	

5.5. *Overall assessment*

During the workshops and beyond, the practitioners expressed direct feedback. This feedback was summarized and clustered into three categories: General (Table 4), Usability (Table 5), and Utility (Table 6). For reasons of comprehension, the comments have been translated from German. There was a focus on the overall evaluation of the instrument. Detailed feedback on bugs, data issues, and feature requests are not included in the collection. Instead, they were continuously documented and, if possible, directly considered in the development process. In Pajares et al. (2021a), a collection of the features requested can be

Fig. 16. New buildings and kindergartens.

Table 6
User feedback - utility.

Positive feedback	Negative feedback
"Useful tool, e.g., to evaluate potential locations for additional bridges over the [local river]".	"Accessibility analyses cannot show the effect of all measures. Sometimes it is more about safety and comfort."
"Good, logical tool that would be beneficial in the early planning stages."	"Application of GOAT rather not possible in rural areas due to poor data availability."
"Well suited for visualization of current planning and as an argumentation aid."	"It would be great if GOAT could be integrated into our existing municipal GIS."
"Well suited for bringing analyses closer to politicians."	"At some places, no calculation was possible."
"Politicians are super grateful for the preparation and visualization of data as it helps to make decisions."	
"With the help of such tools, municipalities could do more planning tasks in-house."	
"This could be a well-respected tool in transport planning, and there would be many use cases for the use of GOAT."	
"High potential of the tool, expansion to whole Germany would be a great added value."	
"Bundling functions (accessibility, visualization, etc.) and various data is an added value for planners."	
"Scenarios are very useful."	
"Very helpful for analyzing the cycling network."	
"Heatmaps are appealing."	
"For location planning and for calculating isochrones to assess accessibility, we could make good use of the tool."	
"We would like to continue to use GOAT for our planning tasks."	

found. Following the feedback, GOAT was assessed as a tool with high potential to be used in practice, but also the need for improvements was raised. The planners saw many use cases to apply the tool and stated that it adds value to the tasks they have to accomplish. As shown in Table 4, they generally liked using GOAT.

The large majority mentioned the instrument is usable (see Table 5), but also some perceived the interface as not intuitive and not self-explaining enough. A clear pattern can be found when tracking the statements back to the users. Participants who spent more time familiarizing themselves with the instrument perceived the tool as easier to use.

Planners from municipalities particularly valued that they could carry out the analyses themselves. They claimed that this helps to present results much faster to politicians compared to outsourcing the analyzes. To carry out studies beyond their municipal boundaries, they would like the tool to be available for neighboring municipalities. Planners from consultancies requested that GOAT should be available for the whole of Germany. They mentioned that it would be necessary to immediately access the tool without spending much time setting it up for their respective study area.

Some practitioners asked for better integration with existing software, such as desktop GIS and data platforms. The need to integrate with existing systems was described to avoid creating a technological silo in terms of software and data. Regarding the access to GOAT, there were different opinions. While some municipalities want to make the tool accessible to citizens, others have concerns about the disclosure and correctness of the data basis. Some representatives of the municipalities mentioned it could be helpful to integrate selected analyses into other existing web maps targeting citizens as users.

6. Discussion and conclusions

This research tried to answer two questions. Suitable use cases for the developed software GOAT should be identified. This was carried out by the involvement of planning practitioners, who proposed relevant planning questions, which were clustered into four groups. The collected list of planning questions cannot be completed by research design. Nevertheless, the different planning questions already cover a wide area. The second research question tries to find answers to whether the developed accessibility instrument is of useful support in practice. This research faces the challenge of having no clear answer to this very complex question.

From the utility perspective, the involved practitioners reported that the analysis is suitable when answering many planning questions. In particular, the ability to perform scenarios was welcomed by the practitioners. Therefore, the request to perform on-the-fly scenario building identified by the COST Action TU 1002 project te Brömmelstroet et al. (2016, 2014); Silva et al. (2017) could be confirmed. Many practitioners mentioned that GOAT could support when assessing changes in infrastructure for walking and cycling, mainly when focusing on accessibility effects of new, modified, or deleted street networks. As the tool interprets accessibility solely time-based, the accessibility analyses fall short when changes in walking or cycling comfort should be modeled. The additional spatial data (e.g., noise levels) provides further insights into the quality of street space.

Furthermore, it can be concluded that many of the tool's features are suitable for assessing the effects of land-use changes. Planners valued the ability to assess local accessibility and identify regions not served by a particular amenity. However, the planners also mentioned that the provided analyses only helped in some of their work and asked for ongoing expansion of the tool. The involvement of practitioners from both urban and transport planning, as well as the general mutual understanding when using GOAT, showed that accessibility can serve as a shared language between often disconnected disciplines, as suggested by Büttner et al. (2018). The usability of the software is vital. During the development, there was constantly the challenge to balance additional functionality and the ease of using the tool. As a result, GOAT might be much easier to use than a classical desktop GIS but is significantly more complex than an easy web map. Accordingly, GOAT can only be used effectively with approximately one day of training. This training can be realized via online tutorials but furthermore through in-person training. Despite the high efforts in making the tool more straightforward, the usability can still be significantly improved. A challenge of the co-creative involvement of the practitioners was that some reported improvements in terms of usability contradicted statements from other users. In general, it is suggested to make separated usability tests that use common methods such as contextual inquiry or session recording. Overall it is concluded that utility cannot be assessed independently from usability. Both criteria in this case study are, instead, often highly interrelated.

During the workshops, the need to combine the training of operating GOAT and practical teaching of the accessibility concept was seen. Many of the involved practitioners have heard of accessibility before, but none of them has used an accessibility instrument before. Similar to the observations of Boisjoly & El-Geneidy (2017) accessibility is generally a known concept in the planning practice, but many have not used accessibility metrics in practice. The study can be seen as a tiny step to make the accessibility concept more known in the local planning practice. Accordingly, the benefits of engagement with the planning practice, which were raised by previous research te Brömmelstroet et al. (2014); Silva et al. (2017), could be confirmed. Although the engagement with citizens using the tool was not tested, the tool is seen as too complex to be easily used by non-professionals. Meanwhile, it is seen as very beneficial to use GOAT in workshops with citizens and political decision-makers while being operated by a planning professional. The concept of seeing the professional as *'chaufeur'* is common from studies using participatory GIS Haklay & Tobón (2003).

The interoperability with existing systems (e.g., desktop GIS, transport models), is an aspect seen as necessary for adopting accessibility instruments in practice. By using standard data formats such as from the Open Geospatial Consortium Open Geospatial Consortium (2022) or by developing software plugins, interoperability can be strengthened. Overall, the continous exchange with the planning practice was a rewarding experience from the authors' perspective and it is suggested to continue on this path.

It is essential to underline the limitations of the presented study. First, the identified use cases were also influenced by the capabilities of GOAT. Many planners knew the scope of the software before and therefore were focusing on solvable planning questions. Accordingly, there might be many more relevant planning questions in the field. Second, the tool was, so far, primarily used in synthetic workshops settings. However, the use of planning software is usually characterized by planners using the software alone. Long-lasting and continuous feedback from planners using GOAT would be needed to produce a more solid picture. Furthermore, the focus was on documenting the experience in worksheets during the workshops. There was also prepared an online survey. However, only very few practitioners participated. Accordingly, the results were not used for the study. Therefore, a collection of anonymous feedback and eventually more honest feedback was not realized. An apparent methodological weakness of the study is that the tool developers themselves carried out the assessment. Self-assessment was great to bring the experience directly into the tool development. However, it also comes with a bias despite following a good scientific practice. It is suggested that independent colleagues assess the usefulness of the instrument in the future.

An eventually trivial aspect is the cost of implementing an accessibility instrument such as GOAT in practice. Despite being an open source tool, it needs to be maintained, hosted, and equipped with the necessary data. Accordingly, it is suggested that future development aiming for fast adoption of accessibility instruments should always keep the necessary resources in mind needed for operating in a real-world environment and the willingness to pay for the analyses. Also, even if mass adopted, the market for accessibility instruments will be a niche with few users compared to other fields in software development. Furthermore, it is crucial to find new in-roads in other domains to tap into new use cases (e.g., real estate development). Finding more use cases might be an appealing idea, not only from the idea of spreading accessibility analyses, but it can generate more resources for better tool development by joining forces in the future.

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