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The TOSCA Case:
How Open-Source Spatial and Digital Decision Support Tools Help Urban Agglomerations to Leapfrog Towards Smart Sustainable Cities

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ABSTRACT

Considering the rapid pace of global urbanization especially in emerging economies of the global South, this article addresses governance approaches for the sustainable development of cities which seek to transform into smart cities. It focuses on leapfrogging as a governance concept for cities thriving towards sustainable development and describes the role of open source digital tools as accelerators for this transition. On such premises, the Toolkit for Open and Sustainable City Planning and Analysis (TOSCA) will be presented as a case study. The paper provides an overview of its conceptualization and implementation in two pilots regions. An overview of the gains and difficulties from the empirical process is discussed, concluding with learnings and challenges for further implementation in other regions, and for the sustainable incorporation of open-source digital tools in urban and regional governance.

KEYWORDS

Decision-Making, Digital Tools, GIS, Global South, Governance, Leapfrogging, Planning, Spatial Data

1. INTRODUCTION

To understand the complexities to be faced in the coming years in the realms of urban and regional governance - especially in developing nations of the Global South - the challenging pace of the world's population growth needs to be acknowledged. According to the UN, an unprecedented and exponential shift of the world population from rural to urban dwellers has taken place since the 1950s. This tendency is expected to accelerate. Estimates hold that by 2050 approximately 90% of this dramatic increase of the world's urban population will be accounted for in the regions of Asia and Africa (UN, 2018). Effective measures are required to mitigate the effects of the imminent urban sprawls that occur especially in rapidly developing regions and emerging economies across the globe.

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These key facts shed light on the urgent need to revise the processes adopted by policy makers to address sustainable urbanization, while recognizing the need to maintain a connection between rural and urban development. The Sustainable Development Goals (SDGs) are an example of globalized means of mitigation for the long-term impacts of rapid urban growth. For example, SDG 16, related to Peace, Justice and Strong Institutions, targets transparency in governance in order to establish security and consolidated development in society (UN, 2022). The achievement of such goals will depend on how effectively these measures can be implemented across the different scales of regulators and institutions, and whether they can reach the most local levels of governance.

To have a deeper view into ground-breaking societal developments, the concept of leapfrogging is a highly relevant approach. Coined almost four decades back (Fudenberg et al.,1983), the term was framed within the scope of industrial organization, addressing the potential streamlining of market and economic growth. However, over recent years, 'Leapfrogging' has been further adopted to other realms of development e.g., technological progress, with remarkable examples in developing regions. In Africa, for example, the rapid take-up of mobile technology allowed the population to have a broader access to information, far surpassing the pace expected by the development of conventional landline infrastructure (World Bank Group; China Development Bank, 2017). Understanding this concept of leapfrogging and its adaptation to a wider spectrum of society and development, its application to, and impact on, the realm of governance is a worthy discussion.

This article will contribute to the understanding of future challenges in the evolution of cities from the Global South which seek their path of transformation towards smart cities, especially through the adoption of digital tools and data infrastructures. The paper thus revolves around the following questions: Can the concept of leapfrogging be transferred to the scope of governance to help cities thrive towards sustainable development? And: How can open source tools accelerate this transition? To address these questions, this paper will introduce the Toolkit for Open and Sustainable City Planning and Analysis (TOSCA) as a case study, providing an overview of its conceptualization and development process as well as its implementation in two pilot locations. The objective is to give empirical evidence of the gains and difficulties from the pilot applications, in order to better address the potential challenges coming ahead for the successful future implementation in other developing regions. Further, the article aims to outline how the sustainable incorporation of open-source digital tools may reduce the gap between local authorities and its population, in the face of procedure constraints on the side of governments.

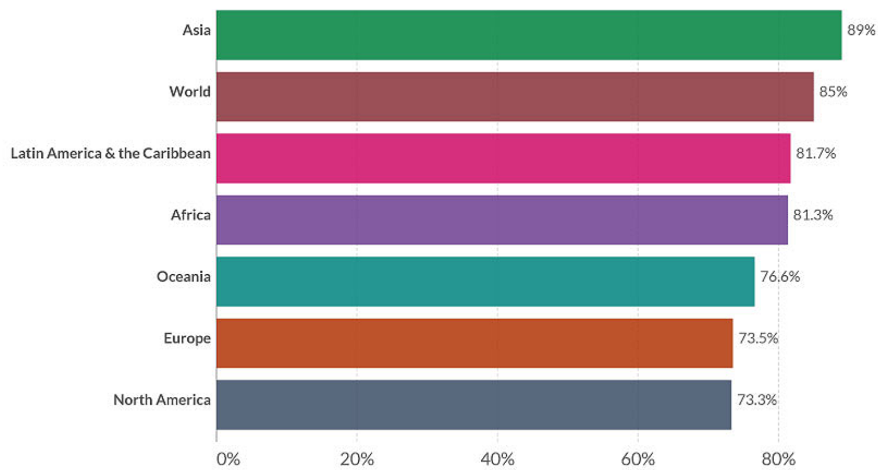
2. BACKGROUND

Several concepts need to be defined to put the proposed questions into context. The following notions form the cornerstones of a theoretical framework that not only supports the targeted application of digital solutions in the urban context but also enables a reflection of their capacity as enablers for swift ("leapfrogging") urban development.

2.1 Urbanization

There is a broad spectrum of definitions aiming to qualify urbanized areas. As explained by Ritchie & Roser (2018) it is not possible to present one universally agreed concept of what defines an urban area; it varies per country according to population density in some cases, or by level of infrastructure development, to name a few parameters. The European Commission, for example, seeks for a more generalized definition, and breaks down this differentiation according to the number of inhabitants and the population density per km^2 (Pesaresi et al., 2016). When comparing different parameters and indexes, the exact worldwide population in urban contexts varies considerably among entities such as the UN and the EC. Nevertheless, the trend of growth is indisputable, having its largest share among Asia, Africa and Latin America, in other words: the developing regions of the global South (Figure 1).

Figure 1. Share of people living in urban areas by region in 2015 (Pesaresi et al., 2016)



Urbanization projections suggest that cities in such developing regions (especially in Africa, East Asia and South Asia) could be the areas that see 96% of an over three billion increase in urban population by 2050 (The Lancet, 2017; Onodugo and Ezeadichie, 2020; UN-Habitat, 2020). Developing regions now have some of the world's largest cities – of 28 megacities in 2018, 16 are in Asia and 4 are in Latin America. To deal with the current explosion of urbanization, policy-makers in these regions experiment with new forms of urban development. In this context, digital ("smart") technologies and infrastructures in support of urban development, planning, and management bear a high potential to mitigate the effects of such trends. Thus, hundreds of smart city projects are currently in progress with e.g., India and Indonesia having programs aiming to establish 100 smart cities each (Arku, 2021).

2.2 Global South and Digital Divide

There is rich scholarship on smart cities in the Global North, however, research on this topic is only now emerging in regards to the Global South (Datta, 2015; Odendaal, 2011; Shin, 2017) (Datta, 2018). Still, the take up of smart city concepts has been extremely fast in the Global South. Developing countries like China, India, Korea and Saudi Arabia are considered the largest consumers of the global smart city market (Manyika et al., 2011) (Datta, 2018).

Technology as a driver of innovation and accelerated progress inevitably also affects societal change (Klynge, 2019). What upcoming challenges are to be faced by nations of the global South in the course of further technological penetration, however, is still a matter of debate. Research has shown that digital breakthroughs in the last years have had stronger impacts in developing countries such as India, Thailand or Mexico than in most developed nations (Klynge, 2019). Also, the sub-Saharan African region has experienced great advancement in the last decades when it comes to mobile technology penetration, allowing not only a more widespread communication, but a stronger influence of ICT in sectors related to governance and economy. Despite such achievements, the emerging digital divide is still a challenge, especially between rural and urban settlements (The World Bank Group, 2017). Although internet access and broadband technology may blur out the digital divide, their adoption needs to be still evaluated on a context-specific basis. An effective way to minimize the digital divide, as it appears, is the transfer of open-source technologies from the Global North to the Global South. Their implementation and deployment, however, still requires a willing and enabling local environment, as well as a clear sense of caution in regards to the threats of techno-colonialism (Yayboke et al., 2017).

2.3 Open Source Tools

Free and open-source tools offer multiple opportunities to support urban planning and development, especially in the light of growing streams of urban data that increasingly fuel the digitization of the planning profession. Thus, new approaches to analyse and synthesize complex and dynamic urban data become increasingly indispensable (Yap et al, 2022). Although the significance of Free and Open Source Software (FOSS) has become well known over the past years, proprietary software solutions are still thriving (Kumar et al., 2018). This situation may be attributed to a lack of understanding of the landscape of available tools and their functionalities, as well as to limited knowledge as to how such tools can add value to the urban planning processes (Yap et al, 2022). The implementation of FOSS in the Global South in the scope of urbanization must tackle several common challenges such as lack of knowledge on GIS, lack of accurate and detailed spatial data (Mennecke & West, 2001), dependence on expensive, proprietary software and vendor lock-in, lack of awareness of open-source alternatives, lack of technically trained people necessary to bring change (Kumar et al., 2018) or dependence on external consultants for carrying out GIS related tasks.

2.4 Leapfrogging

The concept of Leapfrogging, coined from Economics over four decades ago (Fundenberg et al., 1983) was originally used as a metaphor to refer to certain competitive dynamics in the market sector. It referred to the idea of how innovative development models can bypass the traditional paths of economic growth, as established by the industrialized nations. Leapfrogging can also be linked to the predecessor theory of the Diffusion of Innovations from the 1960s (Rogers et al., 2019), where the idea of how innovation spreads through means of communications is also conditioned by additional determining factors like the social system and time.

During the third wave of industrialization, similar concepts relatable to leapfrogging have coincided, such as industrial spurts, related to technology diffusion (Soete, 1985; Pérez & Soete, 1988) which shed light on the fact that the concept is relevant to other fields, like technology, and evidenced its relation to economic growth, thus accelerating progressively its broader application in the following years, and bringing up the concept of technological leapfrogging. Within this idea, the possibility of developing nations to catch up in the adoption of technologies, known as the advantage of the latecomers, comes from the possibility of developing nations to surpass their predecessors by shifting away from the replicated path and seeking innovation in their technology adoption, as they are not bound to the dependency of solid, invested infrastructures (Lee, 2021). To break the pattern of path dependency when adopting technologies differently than developed nations, seems like a logical step, avoiding the failures committed by frontrunner nations, such as fossil fuel consumption and carbon emissions and, thus, contributing to the achievement of sustainable development goals (Lee, 2021).

Aside from the well-known advantages on the uptake of mobile communications technology across Africa, leaving behind the lagging landline network distribution (The World Bank Group, 2017), other relevant applications on technology adoption for economic growth can be mentioned, benefiting different sectors of society, such as the infrastructure or the energy sector (Cilliers, 2021). One example is the investment shift from asphalt for road network recovery, to automated air transportation of goods and services through the implementation of drone technology. Another case is the alternative of green energy generation from atmospheric water harvesting (Jarimi & Riffat, 2020), which would relieve rural areas from centralized water systems and electricity grid supply. Furthermore, the widespread provision of ICT technology has opened the possibility for a larger population to services linked to economy, government, banking and education, making for example informal business shift to formal schemes of market. (Cilliers, 2021).

Despite existing successful cases, it is important to still consider that leapfrogging through technology transfer can only be achieved when - as prerequisites - not only the particularities of each context but also the local technical capacities, political will and bureaucratic feasibility are acknowledged (Yayboke et al., 2017). It is essential to ensure over time that leapfrogging societies can transform from mere consumers to producers of wealth, in order to consolidate sustained growth (Yayboke, 2020).

For developing nations, the economic effects resulting from the use of digital technology is well known. Further exploration, however, is needed to understand the efficacy of digital applications in the realms of governance – especially the impact of open-source tools on urban planning activities and design decision-making. The challenge lies in supporting institutions to adopt new measures and paradigms, especially once original investments were done (Cilliers, 2021). The following discussion of the TOSCA case wants to shed light on how to accelerate this transformational path in cities of the Global South.

3. CASE STUDY: THE TOSCA TOOLKIT

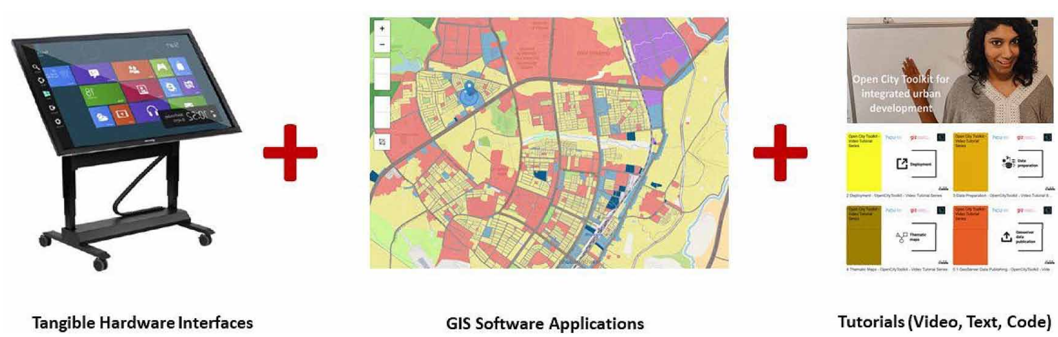
3.1 Conceptualization and Development

The Toolkit for Open and Sustainable City Planning and Analysis (TOSCA) is a cooperation project between the Digital City Science group at HafenCity University Hamburg and the German Agency for International Cooperation (GIZ) Gmbh since 2019. It was piloted in the cities of Bhubaneswar (India) and Latacunga (Ecuador) in 2021. In the first pilot case, the toolkit was tailored for the identification of land for affordable housing in Bhubaneswar, to aid a slum upgradation program within the Sustainable Urban Development – Smart Cities (SUD-SC) program with GIZ India. The second pilot targeted the adoption of volcanic-risk governance strategies in Latacunga within the Sustainable Intermediate Cities program with GIZ Ecuador.

To address the challenges stated in the previous section, TOSCA was conceptualized as a web-based geographic information system (GIS) digital solution that can be used by non-GIS experts. It provides a *scalable, low-cost* and *low-tech* solution (Figure 2) with an easy-to-handle user interface for the interaction of decision-makers from different backgrounds, and to facilitate participatory processes:

- **Scalable:** As an open-source tool, TOSCA is intended to be used by any person or institution and be customized for its specific purpose. The tool´s system architecture follows a modular design that allows the easy incorporation of new analytic modules, as demanded by the specific use-cases. This makes the tool highly scalable and replicable; it can be reproduced any number of times.
- **Low-cost:** The TOSCA software is cost-free and available on the online open source repository GitHub. Online video tutorials support the different kinds of users with guidelines and manuals,

Figure 2. TOSCA components



in order to support the easy take-up of the tool by governments, institutions and individuals with limited resources.

- **Low-tech:** Requiring only basic technical knowledge for the deployment and setup of the tool, TOSCA features an easy-to-handle user interface that minimizes the conventional complexity of GIS systems. TOSCA thus becomes a powerful data visualization tool that also allows the conveyance of complex non-spatial information. Users can upload their own maps or ingest information from Open Street Maps.

These features place TOSCA at an advantage to many open-source tools used in urban planning. The system structure of the TOSCA technology provides the possibility to be taken up from any location where it is needed. It does not have locational constraints on using the tool as it runs on a base of Open Street Maps and can be hosted remotely anywhere worldwide on a web-browser. This enables users to have access to a custom graphic user interface that is easy to understand in comparison with other GIS tools with more complex user interfaces addressing expert users. With a set of video tutorials and manuals publicly available online, the tool can be taken up by planners without the need to be expert programmers but rather with basic knowledge of programming.

Furthermore, TOSCA allows adaptability to become a custom tool for diverse contexts- such as a viewer, finder, analyzer or simulator, depending on the complexity of the use-case. This sets the potential of TOSCA to be used at different phases of a planning process, whether it refers to site analysis, planning, consultation or evaluation. The tool is built with open-source components in a modular manner, allowing quick refactoring of the system architecture if necessary.

As shown in the study on open-source software for urban planning (Yap et al., 2022), geo-spatial analysis and mapping emerged as projects in GitHub with the highest number of stars, which can be considered an indicator of the interest from the GIS-related community to contribute to further technological development. TOSCA, as an open-source web GIS toolkit, has the potential to build an active open-source developer community around it to build it further.

3.2 Technical Modules and Functionalities

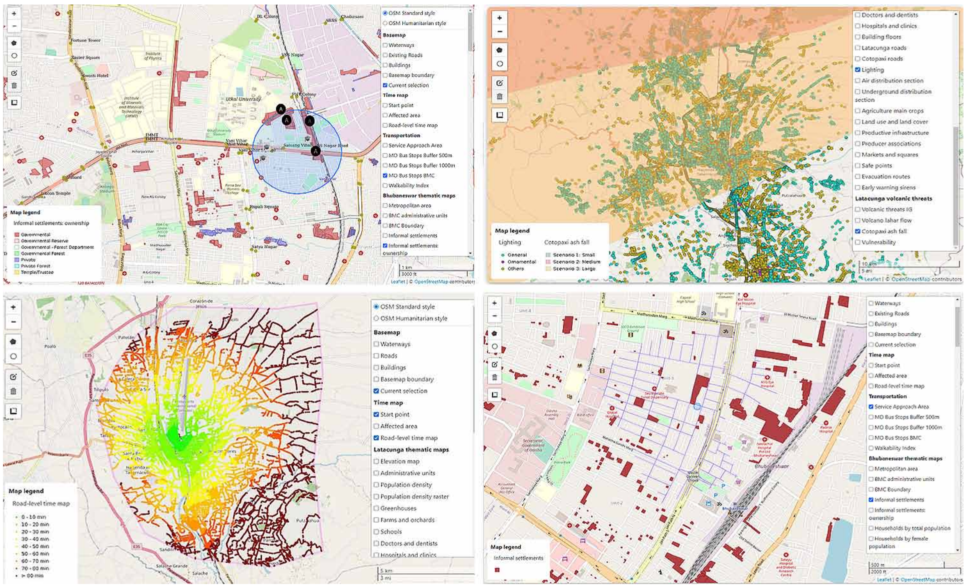
A systematic description of TOSCA needs to comprehend two key aspects: 1) The *functional modules* that represent the capacities of the toolkit as a technological product, and 2) the *use cases* which represent the practical application capacities of the toolkit. Functional modules are generic software solutions which are basically context-agnostic, whereas use cases reflect how these functionalities can be adapted and utilized for specific challenges in specific contexts. These two key aspects indicate the advantages that TOSCA provides as an adaptable and scalable tool, based on its modular design as well as on its cost efficiency and usability.

The easy-to-handle functional modules not only bring non-expert users closer to GIS applications, but also allow the comprehensive visual analysis across different layers of socio-spatial information. It thus facilitates the quick comprehension and analysis of complex urban data e.g., for outlining potential city challenges and conflicts (Figure 3). The appropriate visualization of data substantially enhances the interdisciplinary and multi-level communication between stakeholder groups and decision makers and enables more evidence-based solutions in urban planning and policy making.

Until now (10/2022), the following functional modules have been developed for TOSCA:

- *Map Layer Analysis* for visual data exploration, to a) answer simple questions or b) establish an overview of the available data before analyzing them in more detail with other modules.
- *Feature Query* for investigating in depth and detail the information contained in each individual data layer.
- *Distance and Area Measurement* for measuring and outputting the size of sub-areas and distances drawn between points of interest on the map.

Figure 3. Functional modules of TOSCA: Top left - Buffer module; Top right - Cotopaxi Module; Bottom left: Accessibility Analysis; Bottom right: Feature Query (HCU & GIZ, n.d.)



- *Accessibility Analysis* for creating a heat-map showing travel times for vehicles, bikes, or pedestrians from given start points within a selected area e.g. under disaster conditions.
- *Deep Area Query* for complex filtering of map features and elements on the basis of user-defined values.
- *Area Buffer Analysis* for investigating points of interest within a specified buffer radius from a location selected on the map.
- *Cotopaxi Eruption Scenario Analysis* for the specific risk assessment of Ecuadorian city Latacunga´s agricultural and urban infrastructure in the face of volcanic eruption.

3.3 Pilot Applications and Use Cases

In order to apply TOSCA successfully, specific use cases need to be defined in the early phases of any implementation project. To identify, clarify and organize the functional requirements towards the toolkit, complex communication and interaction processes have to be carried out with local actors and stakeholders e.g., collective brainstorming, problem discussions, or structured information collection. Use cases may be infinite but may be addressed by the above-mentioned functionalities. In addition, new functionalities are continuously being developed and will be further developed in the future. Since the conceptualization of TOSCA, two pilot applications have been accomplished in India and Ecuador, from which first use cases were derived for the toolkit.

Small and medium cities play a crucial role in advancing sustainable urban development and, due to their scale, are able to provide basic needs more effectively in comparison to larger metropolitan areas or megacities (Intermediary cities. (n.d.). UCLG). The characteristics of proximity and human scale of smaller urban centers can be leveraged to strengthen urban capacities and prevent urban sprawl. The cities of Bhubaneswar and Latacunga both fall into this category of cities and provide unique challenges that can be addressed by piloting TOSCA for the respective use-cases.

3.3.1 Pilot Application: Bhubaneswar (India)

India is estimated to be the largest contributor to new urban dwellers worldwide by 2050 (UN, 2014), thus it was imperative to consolidate innovative design policies for Bhubaneswar which can ideally be replicated to other regions in the country. In the context of the city of Bhubaneswar – located in India's southern state of Odisha – TOSCA was requested to identify land for construction of affordable housing to relieve the dramatic growth of the slum population (Anand, & Deb, 2017). The goal was to allocate 100,000 new housing units in the city. The involved actors were the Commissioner Office, Bhubaneswar Municipal Corporation (BMC), supported by the Bhubaneswar Development Authority (BDA) and Bhubaneswar Smart City Limited (BSCL). The support of the local authorities was crucial for the successful pilot phase in India. The physical deployment of the tool was done in the headquarters of the BMC while the BDA and BSCL supported the pilot project with the provision of reliable and available geospatial data.

3.3.2 Pilot Application: Latacunga (Ecuador)

The pilot application in the city of Latacunga in Ecuador focused on the identification of strategies to strengthen volcanic risk governance measures in the region due to the presence of the active Cotopaxi volcano and the great economic dependency of the region due to its agricultural activity. The 2015 volcanic eruption in Latacunga exposed the need of the city to understand the physical, social and systemic vulnerabilities (Gomez-Zapata et al., 2021) faced by Latacunga, especially as another major eruption risk is imminent, according to experts. Over 300,000 residents in the region are exposed to this high volcanic threat. The main user of the toolkit in this case was the Municipality of Latacunga with the departments of Planning, Citizen Security and Risk Management, Public Works and Environment and the Cotopaxi Prefecture, in the scale of provincial government. Additional organizations capable of generating technological innovation could take part in the participatory processes, such as Coworking Latacunga and Instituto Cotopaxi, a local research center focusing on the investigation of environmental hazards and risks mitigation, among others.

3.3.3 Use Cases

In terms of practical application, there are two general scenarios for the application of TOSCA in the context of urban planning and decision-making, from which specific use cases and usage requirements derive:

1. **Expert discussions and decision-making:** Interacting with complex urban data such as legal planning frameworks, planning information, or infrastructural systems, without necessarily having expertise in Geographic Information Systems (GIS).
2. **Multi-stakeholder participation and deliberation:** Effectively involving the broad citizenship into urban development planning projects in order to address their needs and ensure their engagement and participation in the decision-making and acceptance-finding processes.

Being implemented with either scenario, the specific use cases for the TOSCA toolkit were found by intersecting the concrete application contexts in the pilot cities of Bhubaneswar and Latacunga with the available functional modules. The following list (Table 1) indicates the implemented or conceptualized use cases so far; other use cases - in respect to new application contexts and new functionalities are being constantly explored.

3.4 Methodology and Implementation

In both pilot locations, a similar methodology was carried for the first practical implementation of TOSCA. While similar activities were considered, special care was taken to maintain a suitable adaptation to the specific contexts of both pilot cities. The step-by-step guideline for the piloting in

Table 1. Example module analyses implemented in both pilot cities with TOSCA (Authors, 2022)

	Pilot City: Latacunga (Ecuador)	**Pilot City: Bhubaneswar (India)**
Module: **Map Layer Analysis**	Show the streetlights that are located within the area potentially affected by volcanic ashfall from a Cotopaxi eruption.	How many slums are currently located within open spaces or vacant land? / What kind of ownership do these lands have?
Module: **Feature Query**	Show the details of a specific market - The type of market (e.g. wholesale), days of opening of the market, status of the building and land area of the market	Which slums are currently occupying government-owned land?
Module: **Distance and Area Measurement**	What is the distance between two street lights?	What is the land area occupied by a specific informal settlement?
Module: **Accessibility Analysis**	How long does it take from different areas in the city to one of the safe points? / How is the accessibility from different areas of the city to the safe points affected by lahar flows from a Cotopaxi eruption?	How long does it take to reach a cluster of informal settlements from a bus stop?
Module: **Deep Area Query**	Which agricultural areas producing broccoli are potentially affected by ash fall (medium impact scenario)?	Filter the map to show those houses with a monthly household income between 2.000 and 3.000 USD and min. 5 persons living in the household / Filter the map to show those areas with a social vulnerability index between 4 and 5 and a high population density.
Module: **Area Buffer Analysis**	Not yet applied in this use case	How many hospitals are located within a 1-kilometer radius from a proposed slum relocation area chosen to rehabilitate slum dwellers?
Module: **Cotopaxi Eruption Scenario Analysis**	Which specific evacuation routes are potentially affected by lava flows and what are their attributes (e.g. ID, length)? / Which productive infrastructure is located in areas potentially affected by lahar flows (high risk) and what are its attributes (e.g. ID, area size, type)? /	Not applicable to this use case

India and Ecuador is outlined below. For each of the 10 steps, it provides a brief explanation of the aspects to be considered, thus forming a prototypical implementation methodology:

1. **Identification of City and Use Case:** Fundamental aspects to select a particular use-case and city are: 1) access to relevant data suitable for the tool; 2) strong institutional capacity and willingness of the local government to use TOSCA and integrate it into workflows for decision-making; 3) reliable network of local partners with ownership, interest and commitment; 4) practical use cases linked to existing projects and based on the socio-economic context of the city.
2. **Mobilization of Project Support Team:** Different types of human resources are required to implement TOSCA in a sustainable manner. These would ensure an extended use of the tool after the end-of-project phase. The following roles should be considered:
    a. **Local non-tech support:** Coordinating the project implementation and ensuring commitment by local core stakeholders.
    b. **Local tech support:** Technically implementing the project and adapting the tool to the local context.

   c. **Long-term host:** Ensuring take-up through hosting, operation and maintenance of the system in the longer run.
   d. **Scientific access point:** Linking to the technological and scientific community, providing consultancy and software development.
3. **Hardware Acquisition:** Hardware acquisition should be done together with the local stakeholders, as early as possible and in line with the local capacities and availability. In accordance with the original project concept of TOSCA, any local self-fabrication of the interactive user interfaces (e.g. with *makespaces* or tech communities) is preferred over a mere purchase of commercial end products. This allows for later repair, demand-specific customization, and easier maintenance.
4. **Mobilization of Local Stakeholders:** The involvement not only of the core partners of each project but also the indirect stakeholders, from the beginning, is essential to define a unified goal for the use case, and also to set up a clear definition of the role and degree of involvement of each of the parts. Furthermore, to ensure the sustained take-up of the tool locally, it is essential to adapt the tool to the needs and demands of the local users. Table 2 illustrates an example of relevant stakeholders and their potential contributions to the project.
5. **Use case definition:** The precise and in-depth definition of a use case is a critical task executed collaboratively with the identified stakeholders. It is a dialogical process best carried out in workshops which target the definition and convergence of requirements. Use case definition is about bringing data, use case questions and tool functionality together. Taking the India example, one use case was 'Identification of land for the construction of adequate housing'. Here, it was required to link the use case question (Which slum areas are in biggest need for upgrading?) to the existing datasets (Access to water / electricity, Land ownership) and the existing or requested functionality (Query Module for filtering out slum areas with the least access to amenities).
6. **Data Preparation:** In this crucial step, the requisite data sources are screened and prepared. Without access to relevant and up-to-date datasets of sufficient quality, TOSCA is only of limited use. The project support team should mobilize their networks to get access to available data, and motivate higher-level decision makers to provide and share necessary data. Open source data

Table 2. Example of implemented Stakeholder Mapping Table, according to role and compromise to the project (Authors, 2022)

	WHAT						
WHO	Political support & commitment to participatory planning	Provision of data	Main user of the tool and lead of participatory process	Involvement in participatory planning process	Technical Development and knowledge transfer	Upscaling & further development	Hosting and Maintenance
Central and regional government	X	X	X				
Local Government	X	X	X				
Municipal service providers, such as mobility and services operators		X	X			X	X
Planners affiliated to relevant Ministries			X			X	X
Private developers and investors		X		X			
Scientific and Academic Institutions				X	X	X	
Governance Support Agencies	X			X	X	X	
Interest groups, citizens, civil society and local communities		X	X	X			

should also be explored. The compiled datasets need to be prepared and imported to the TOSCA system. This requires technical expertise in data management and data science, especially in regards to geospatial datasets.

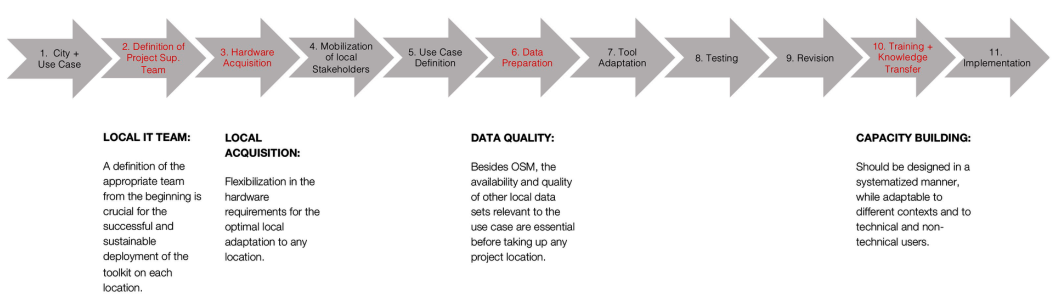
7. **Tool Adaptation:** The necessary adaptation of the tool may include the creation of new analytic software modules, improvements in the existing functionalities, and adaption or translation of the user interaction process. Based on the outcome of the use case specification, it should be clear if further modules or functionalities need to be developed to conduct the necessary analyses.
8. **Testing and Revision:** The functionality and usability of the tool is tested by observing how representative users interact with the tool and attempt to complete expected tasks with it. This testing step should be done with those stakeholders who will be the final users of the tool. The development team should assess the validity of the feedback, formulate solutions, and allocate adequate time for improvements. Additional communication between developers and users might be necessary to clarify requirements.
9. **Training and Knowledge Transfer:** A technical handover needs to be carried out in order to ensure the appropriate knowledge transfer to the local partners. An extensive documentation has been produced to facilitate the use and maintenance of the tool, i.e. user manual, administrator's guide, the GitHub code repository and an online platform with video tutorials. Additional online training and Q&A sessions may be organized to strengthen local capacities.
10. **Implementation and Learnings:** This last phase involves the technical set-up and hosting of the tool, as well as the practical long-term usage of the tool, for example in expert discussions, workshops or multi-stakeholder participation campaigns. A key decision at this point is the assignment of the responsibility for the longer-term maintenance of the tool and its data.

4. RESULT AND FINDINGS

The implementation of TOSCA in the two pilot locations revealed three critical issues along the implementation process as described in section 3. Besides the opportunity to further develop the capacity building within the project, following aspects need to be considered in detail: 1) The role of stakeholders, 2) the local technical capacities, 3) the accessibility and openness of data (Figure 4):

- **Role of Stakeholders:** The implementation of TOSCA in the two cities shed light on the need to define more precisely the role and needs of the stakeholders from the beginning to tailor the toolkit to the specific use case context. In addition, it exposed differences in the dynamics of the take-up processes in both cases. In India, the tool saw a faster take-up technically thanks to the local capacities. Nevertheless, the tool remained within the public administration system, which conditions the broadness of its use. In the case of Ecuador, the tool was successfully taken-up and put to use after the end-of-project, thanks to the interest of one of the local research partners,

Figure 4. Implementation methodology: Criticality points in the piloting process (Authors, 2022)



resulting in a higher dissemination among different stakeholders. However, the local stakeholders in this location have manifested their need to receive further capacity building to go further with the tool. This could be attributed to the type of stakeholder in Ecuador which was an academic research institute instead of a public administration office. Thus, the presence of institutional partners with interest in exploitation measures is crucial in long term take-up of the toolkit.

- **Local Technical Capacities:** The fast take-up of the tool in India and consequent development of further technical modules (such as the buffer tool) highlight the strength of the existing IT ecosystem that circumvented the usual hurdles in other countries of the Global South, related to the lack of technically trained people. In the case of Ecuador - where the toolkit saw a stronger take-up by different institutions - lesser technical advancement was observed though.
- **Access and Openness of Data:** The access to data was quite different in both contexts. In India, there was abundant availability of data due to previous urban programs where GIS data on slums had been collected. In Ecuador, the data availability was limited and institutions were skeptical to share data due to privacy issues. In general, the time and expertise needed for the data preparation phase should not be underestimated. The teams in India and Ecuador encountered a number of challenges:
    - Data sources were spread across different departments, difficulty to collect information, access to spatial data was a huge challenge, high dependence on partner organizations, intervention from higher authorities were required to solve these issues. Thus, use cases should be chosen based on availability of data.
    - Data compilation and preparation was quite an extensive task. Direct access to partners by the technology team would have been helpful. Data was also not up to date.
    - Some public institutions were hesitant to share data.
    - The data was scattered and complex to retrieve.
    - Institutions did not have the data needed specifically for the tool, lack of availability of data in the requested format was also an issue.
    - There is a lack of institutional capacity to handle open data. Few institutions have repositories that are interconnected to exchange information.
    - Central governments struggle to update and collect data, and to acquire GIS equipment.
    - Many institutions were afraid to share their data, due to privacy issues but also to not show their shortcomings. Convincing local governments to share data is critical; this needs to be accounted for in future cases.

5. CONCLUSION AND FUTURE CHALLENGES

TOSCA has proven to be a relevant instrument for sustainable planning and development. It presents itself as a potential means for leapfrogging the urban planning practices in cities of the Global South and emerging economies towards intelligent digital (“smart”) cities. Nevertheless, the toolkit and its application still hold space for further technological and implementational development. Next application and pilot cases of TOSCA should aim at improving the following aspects:

- **Measuring Impact:** In order to better understand the impact that a toolkit like TOSCA can have in the sustainable development of cities, quantitative and qualitative measures are needed to understand its effects on the planning of cities, in the short, medium and longer term. Key Performance Indicators under the framework of the SDG 11 (Sustainable Cities and Communities), SDG 16 (Peace, Justice and Strong Institutions) are relevant for pushing forward more sustainable governance models.
- **Open Source Community:** Consolidating an open-source community platform would strengthen the conceptual as well as the practical disposition of TOSCA, and allow for its fast dissemination

across many geographical locations. Furthermore, it would contribute to the development and exchange of new use cases and modules and, thus, accelerate the technological innovations and explorations of the toolkit.

- **Knowledge Transfer:** Capacity building as an indispensable task for the success of TOSCA will reduce the risk of the toolkit not being taken-up by local authorities, institutions or communities. TOSCA maintains to be an accessible tool in terms of cost, technology and skills. The documentation for training the usage of the tool was one of the strongest project assets, according to the local partners in India and Ecuador. To further strengthen the knowledge transfer and exchange of experiences between the different pilot cities, the provision of personalized training and a direct contact channel for additional questions, as well as the inclusion of guidance on the programming of new modules are potential pathways. A core focus of upcoming TOSCA projects is on capacity-building of local partners, for which a systematized process shall be established which is adaptable to different contexts, cultural backgrounds and expertise levels.
- **Exchange Between Pilot Cities:** Since its pilot projects, TOSCA has raised interest in other contexts and branches out to further locations and applications. This opens the opportunity for establishing a knowledge and experience exchange among the locations of past, ongoing and future TOSCA applications. To consider a direct contact channel of exchange and communication among the active users of the toolkit across different levels, from the academic, technological or institutional realms, can also have a leapfrogging effect on the acceptance of the tool and consolidate its integration as a supporting planning tool.

One of the concrete outcomes of the implementation of TOSCA, is the positive result after completing the two pilot cases, where the need for follow-up projects was demanded on behalf of the local stakeholders, either on neighboring cities or for the purpose of extending the capacity building activities. For example, in the case of Latacunga, its most tangible contribution has been the consolidated ongoing collaborative support between the local government, research institutions and the higher-level education sector, towards the development of new use cases to address local challenges in the city. Another tangible result from the implementation of TOSCA, in this case in India, has been the request to replicate the technology in the upcoming months in other cities, where once again the development of the use cases will be carried out in cooperation with the local Public Authorities. This consolidates the need for such complementary tools to address urban challenges in the region, and will allow for further explorations in terms of development and impact assessment of the tool.

Thinking critically about the relevance of TOSCA as a means to help cities leapfrog towards sustainable growth, the theory of the Diffusion of Innovations (Rogers et al., 2019) can be taken under account and reviewed further, as a precursor of the concept of leapfrogging. If the distinctive aspects of the diffusion research consist of five main elements involved in the spread of a new idea, these being the innovation in itself, the adopters of the idea, the dissemination, time and an appropriate social system to adopt it; it is worth reflecting on the idea that in the case of TOSCA some of the elements have been addressed, and finally the element of time is fundamental to understand its successful take-up and impact in the coming years.

Overall, TOSCA can advocate for the importance of achieving the use of open data in urban development and thus consolidate transparency and trust in governance, benefiting its executors and ultimately the broader population. Through sustained collaborative participation and incorporation of citizens' demands, TOSCA can enhance multi-stakeholder exchange and achieve a higher level of political literacy in the general population in the longer term. Through its pilot applications, the toolkit has demonstrated the gains from using data in a shared manner and its value for decision-making processes across multiple planning levels. Having become an accelerator for the digitalization across various sectors of local governance, TOSCA can stand as a relevant case study for how open technologies linked to governance processes can support the leapfrog transformation of cities in the Global South.

COMPETING INTERESTS

All authors of this article declare there are no competing interests.

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