Scaling Up Innovative Participatory Design for Public Transportation Planning: Lessons from Experiments in the Global South

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ABSTRACT

New data, new technologies, and greater computational power are changing the possibilities for involving stakeholders in transportation planning. This paper explores these possibilities by comparing deployments of an interactive web-based public transportation mapping system in four cities of the Global South. Structured workshops focused on different public transportation improvement projects and involved different types of stakeholders. Despite the differences across the workshops, they allow for some comparison of the effects. In terms of the technology itself, participants broadly agreed about its usefulness and usability. Pre-/post-workshop surveys suggest that participants learned about the transportation projects presented but reveal modest evidence regarding other impacts, such as learning about the concept of accessibility, and gaining an appreciation for the potential broader urban system impacts of public transport projects. Knowledge among the participants tended to converge and the tool helped promote dialogue among participants and generated some empathy for others. The workshop experiences provide some hope for such tools in enhancing public transportation planning processes, globally, but "scaling up" the technology would need to overcome institutional, technical, and procedural challenges.

1. INTRODUCTION

Urban mobility planning is in an era marked by a range of important changes. Theoretically, accessibility – the potential for individuals/firms to access their daily wants and needs – has become increasingly recognized as the objective of our mobility systems. Mobility is a "means" to enabling accessibility, the "ends" (e.g., 1, 2). Practice has followed in this direction, albeit more slowly, due to institutional and political inertia and technical complexity (2). Technologically, digitalization is transforming mobility services and also producing new data, open data and open source tools, and greater computational power (3). Societally, citizens around the world increasingly expect meaningful access to all aspects of the planning process (3).

This paper explores the confluence of these trends through the lens of public engagement for transportation planning in the Global South. In theory, public engagement can bring a range of benefits to planning, incorporating a broader range of knowledge and experiences, helping to understand preferences, advancing fairness and justice, and, ultimately, gaining legitimacy for decisions (4). Nevertheless, engaging the public in public transportation planning poses various challenges (5). It can add up-front time and cost to the planning process. It requires new skills, capabilities and procedures, to ensure productive dialog, in which different stakeholders have an equal opportunity to contribute in timely and meaningful ways. It also faces technical barriers, since transportation planning traditionally utilizes complex models to predict outcomes. These tools – often criticized as "black boxes" – can further hamper inclusive engagement (3).

Recent advances in computational power and graphical user interfaces offer some promise to open up the "black box" and make transportation planning more interactive and widely understandable (3). Literature on collaborative spatial modeling tools suggests that the substantive content of the models and the quality of participatory interactions they support can affect engagement outcomes (6). Navas (7) refers to these tools, generally, as accessibility-based visualization tools (ABVT) and highlights their potential to bridge communication gaps, thereby enabling mutual understanding about potential impacts and "increasing the legitimacy of the planning process" (p.19). This is consistent with others' perspectives regarding the potential for "technologies of representation" (8).

One such ABVT is CoAXs (Collaborative Accessibility-based stakeholder engagement system). CoAXs draws on accessibility concepts to support shared understanding among and between planning officials, key stakeholders, and members of the general public. CoAXs uses spatial representation and an interactive user interface to allow users to modify and test public transport scenarios iteratively and compare impacts across locations (9). CoAXs calculates and displays cumulative opportunity-based accessibility measures. These can be displayed as isochrones on a map, delineating the area that can be reached within a chosen amount of time from a specific spot, and as numerical summaries of the number of opportunities reachable within that amount of time from that spot (e.g., number of jobs within 30 minutes). Cumulative opportunity measures are relatively straightforward to calculate with modest data needs and intuitive to understand. Compared to other accessibility measures, however, they less effectively represent empirically based information on dislike for travel (as gravity-based measures can do) or individual preferences and constraints (as utility-based measures can do) (e.g., 1).

CoAXs was originally piloted in focus group settings in Boston (MA, USA) and Santiago (Chile) (10). The technology and implementation approach were subsequently refined in public workshops carried out in Boston (3, 6). These workshops deployed CoAXs on large touchscreens and allowed users, in small groups (of 6 to 10), to examine: in the first instance, changes to proposed bus rapid transit (BRT) corridors; and, in the second instance, bus priority infrastructure on five corridors. The workshops were run by trained facilitators in both cases.

CoAXs requires two types of input data: the General Transit Feed Specification (GTFS) of the structure and schedule of a city's public transport system, and georeferenced data of opportunities such as jobs, schools, and/or public facilities. Combined, these inputs allow users to calculate cumulative opportunity-based accessibility measures for public transport from any selected spot in the city. The interface allows users to compare a baseline situation with scenarios that represent variations in public transport services. The travel time and accessibility calculations draw from the Conveyal R5 routing engine and Analysis platform (11), open-source software that utilizes GTFS and accepts scenario modification and routing requests. Relative to more sophisticated ABVTs, such as Conveyal's (11), CoAXs' user interface sacrifices details related to precision and, especially, resolution in public transport service parameters to enhance ease of use among a broad range of stakeholders.

The Boston CoAXs implementations indicated that users found the tool to be relevant and credible (3), supporting social learning, group alignment and imagination (6). These experiences suggest some potential for tools like CoAXs to enhance stakeholder engagement in the USA. What role, however, might they play in cities of the Global South? Can they be usefully employed to help improve stakeholder engagement? What impacts might the tools have on participants and their perceptions of public transport options and the planning process? Finally, what do CoAXs applications in the Global South suggest regarding the widespread adoption of such tools? In an attempt to answer these questions, this paper summarizes findings from experiments in four cities: three in South America (Santiago, Chile; Concepción, Chile; and Bogotá, Colombia) and one in Africa (Tshwane, which includes the city of Pretoria, South Africa).

2. EXPECTATIONS AND METHODS

A tool like CoAXs may be especially valuable in the Global South, where cities tend to have a higher public transport mode share, and thus more stakeholders interested in transit projects. Furthermore, travel conditions tend to be worse in developing cities where infrastructure investments and system management lag motorization. Lower income residents especially suffer, since they are highly dependent on public transport and often live in transit-poor areas on the urban peripheries (12).

Despite their promise, participatory tools like CoAXs might face numerous challenges. Data, both GTFS representing the public transport system and data representing opportunities (e.g., jobs), may be low quality or non-existent. Developing cities may exhibit more severe inequality and class tensions, which could complicate efforts to build consensus and discourage engagement. An analogous "Digital Divide" may also be more severe in developing cities, leaving some participants less able to understand and interact with tools like CoAXs. Younger democracies may suffer from higher levels of distrust of government which might dissuade participation (13). In addition, participation in transportation planning may face the "traditional view" that decisions are best left to the "experts" (14). Relatedly, the necessary institutional arrangements and commitments to sustain participatory planning may be lacking (15, 16).

To examine the potential impacts of the CoAXs approach in the Global South, we ran facilitated workshops in four cities, drawing directly from the Boston experiences. CoAXs was deployed on a large touchscreen (in the Tshwane case, a laptop version was also available) to encourage group interaction. In each case, we utilized pre-/post-workshop surveys to measure changes among participants. The questions were adapted from previous experiences which drew from relevant literature (3,6,7,18). We kept as many survey questions identical across cities as possible, although differences in transport project types, time availability, and language necessitated some variation. Additional information was obtained from workshop observations and facilitated discussions.

We expected that CoAXs would improve understanding of the public transport projects, change perceptions of the expected impacts, increase enthusiasm for the projects, and help learning about related concepts, especially accessibility. We also expected to see some convergence in the perspectives of government officials and the general public. To compare changes in responses between the pre- and post-workshop surveys, we use the Wilcoxon signed-rank test. To determine if responses differed across the different groups of participants, we use the Mann-Whitney U test. Additional details on the Santiago case can be found in (7) and (17) and on the Tshwane case in (18) and (19).

2.1. Workshop Contexts

On basic socioeconomic and demographic characteristics (Table 1), Santiago and Bogotá are relatively large (7-9 million persons), Tshwane is “mid-size” (3.3 million), and Concepción is “small” (under one million). Chile is an upper middle-income country, with “very high” human development as characterized by the Human Development Index (HDI); Bogotá and Tshwane come from countries with similar levels of GDP per capita, although Colombia has a somewhat higher HDI measure. Chile and Colombia have similar measures of income inequality while South Africa’s measure is considerably higher. Despite variations in vehicle ownership in the cities, each still has relatively high public transport mode share.

Table 1. Basic Demographic and Socioeconomic Indicators

Metropolitan Area	Pop. (000s)	National			Public Transport Mode Share[e]	Cars/HH Veh/1000 pers[e]
		GDP/Cap (US$)[c]	HDI[d]	Gini Coefficient[c]		
Santiago	7,182[a]	15,923	0.83	46.6	32% (2012)	0.58 223 (2015)
Concepción	992[a]	15,923	0.83	46.6	41% (2015)	0.52 205 (2015)
Tshwane	3,275[b]	6,337	0.70	63.0	48% (2011)	0.55 172 (2015)
Bogotá	8,953[a]	6,651	0.75	49.7	43% (2015)	146

a. 2015 (20); b. 2016 (21); c. (22); d. Human Development Index, (23); e. (24), (25), (26).

Since deployment of a tool like CoAXs is inherently a sociotechnical endeavor, we also broadly compare the national contexts, along some relevant dimensions (Table 2). These wider exogenous factors might contribute to variations in CoAXs’ usefulness and impacts across places. One important dimension relates to a nation’s political context, since participation in planning involves “the subtleties and intricacies of democracy” (27; p. 432).

Although little evidence exists regarding the relationships between governance systems and participatory processes' quality or outcomes (e.g., 28), we would expect more democratic societies to be more open to participatory processes. By one measure of democracy (29), the countries measure high relative to regional peers and fall within the top one-third of the world's democracy rankings (Chile, 23rd; S. Africa, 40th; Colombia, 51st; as reference, USA is 25th). These rankings are consistent with other global measures (e.g., 30). Chile and Colombia measure relatively low on political participation, which includes indicators such as voter turnout and women in Parliament. By one measure (31), Chile is perceived as the least corrupt of the three nations. Based on these indicators, we might expect Chile to be more inclined towards participatory planning processes.

Broader cultural values also influence a particular society's approach to a problem, although measuring and comparing relevant cultural aspects can be a challenge. Drawing from Hofstede's landmark study of national culture (32), the three countries' culture scores (33) provide no clear a priori expectation regarding CoAXs adaptation. We might expect a slightly higher cultural predisposition in South Africa, based on its measures of tolerance for inequality, uncertainty avoidance and long-term orientation.

Finally, since CoAXs involves technology among participants, we attempt to measure each country's tech-savviness. First, we use the International Telecommunication Union's (ITU) ICT "Index", which measures access to ICT, ICT use, and ICT skills. By these indices (34), Chile ranks highest, 56th among 176 ranked nations, while Colombia and South Africa have similar scores and rankings (ranked 84th and 92nd, respectively). Other measures of "tech-savviness" (35, 36), albeit less institutionalized than those of the ITU, show somewhat similar results (in terms of the quality and quantity of computer programmers and developers), also favoring Chile's likelihood of successful deployment.

Table 2. Indicators of Democracy, Culture and Technical Capacity (values in *italics* indicate strongest measure "in favor" of ABVT)

	Indicators	Definition	An increase in participation via ABVT expected with:	Chile	South Africa	Colombia
Democracy Indicators	Democracy Index[a]	Composite measure of democracy	More democratic societies	*7.97*	7.24	6.96
	Electoral Process, Pluralism	Free, fair, open processes	More open political processes	*9.58*	7.42	9.17
	Functioning Government	Elected government with relevant powers	Better functioning government	*8.57*	7.5	6.79
	Political Participation	Voter participation, engagement	Broader political participation	4.44	*8.33*	5
	Political Culture	Social perceptions of democracy	Higher democratic perceptions	*8.13*	5	5.63
	Civil Liberties	Various freedoms (media, association, etc.)	Greater civil liberties	*9.12*	7.94	8.24
	Corruption Perception Index[b]	Perceived levels of public corruption	Perceptions of "cleaner" govt.	67	43	36
Cultural Indicators[c]	Power Distance	Tolerance for inequality & authority	Lower tolerance	63	*49*	67
	Individualism	Preference for loose-knit social framework	Ambiguous[d]	23	65	13
	Masculinity	More competitive, less consensus-oriented	Lower values	*28*	63	64
	Uncertainty Avoidance	Rigid codes of belief and behavior	Lower values	86	*49*	80
	Long Term Orientation	Prepare for future through thrift, education	Higher values	*31*	*34*	13
	Indulgence	Relatively free gratification	Higher values	68	63	*83*
Technical Capacity	ICT Development Index (IDI)[e]	Multi-indicator measure of nation's state of information and communication tech.	A more 'techo-literate' society	*6.57*	4.96	5.36
	Access sub-Index	ICT access indicators (e.g., international bandwidth penetration, households with computers and internet access)	Greater ICT access	*6.79*	5.48	5.88
	Use sub-Index	ICT usage intensity indicators (e.g., broadband subscriptions)	Greater ICT use	*5.39*	3.91	4.11
	Skills sub-Index	Different indicators of educational achievement	Higher ICT skills	*8.49*	6	6.81
	HackerRank	"Best Developer" Index[f]	A more 'techo-literate' society	*78.4*	68.3	66
	GitHub Account density	Accounts per 1M inhabitants[g]	A more 'techno-literate' society	*373*	191	208

Sources: a. (29); b. (31) (higher levels indicate less corrupt; 2018). c. (33); d. more "individualistic" society might be more inclined to participate, as might be a more "group-oriented"; e. (34); f. an average of standardized scores for countries, assessing individuals' accuracy and speed in responding to coding challenges posted to HackerRank website (35); g. based on publicly active geo-located GitHub accounts (over past 7 years) (36).

2.2. Scaling Up?

CoAXs was designed to be free and open-source software (FOSS), so that it could be readily adapted and applied by a variety of users in different contexts. Nonetheless, this objective faces challenges. Most FOSS requires a critical mass of users and developers in order to scale (37). Since CoAXs is relatively complex compared to many FOSS libraries and plug-ins, it will require a substantial user base to reach critical mass. We use the workshop experiences and a literature review of FOSS to identify strategies for scaling CoAXs in and beyond the Global South.

3. WORKSHOP APPROACHES AND FINDINGS

We adapted the CoAXs approach from the Boston experiments to the new contexts: a 30-minute introduction to the projects and the tool, 15 minutes for the pre-survey, 45-60 minutes of examining the projects with the tool, 15 minutes for the post-survey, and 30 minutes for a debrief discussion. Across cities, the implementation approach varied in several dimensions, including intended audiences and context-specific purposes (Table 3).

Santiago had two workshops: one with “decision-makers” (government officials in the realms of mobility and urban development) and one with “stakeholders” (representatives from relevant advocacy organizations). CoAXs included seven different public transportation projects, chosen due to their metropolitan scope and likelihood of implementation: new metro lines, a cable car, a tramway, a suburban rail line, and bus improvements. Concepción involved three workshops: one with government “technical experts” and two with stakeholders (public transport users and members of community organizations). CoAXs included 13 exclusive-lane bus corridors. The Tshwane case examined a contentious proposal for a new bus priority route and included two alternatives: operating in mixed traffic or on an exclusive lane (BRT); the latter included an additional alternative of having feeder routes serving the BRT. Tshwane entailed four workshops, two with local residents from neighborhoods surrounding the corridor and two with university students (part of the corridor operates adjacent to the university). Finally, Bogotá represented the most unique case. The local public transport agency preferred an internal workshop among its staff and, rather than using the CoAXs interface, used Conveyal’s Analysis user interface directly. So, the Bogotá case involved a single workshop with professionals, analyzing the integration of Bogotá’s semi-formal public transport system with the “formal” *Sistema Integrado de Transporte Público* (SITP).

Table 3. Key workshop details

City	**Date**	**Officials**	**Public**	**Type of Public Transport Project(s)**	**Types of opportunities (for accessibility)**	**Workshop-Specific Research Question(s)**
Santiago	June, 2017	6	9	Metro, bus, suburban rail, cable car	Jobs, health facilities and education centers (primary and secondary)	Can CoAXs improve engagement and planning processes; can CoAXs generate greater metropolitan-scale "understanding" among users; what differences between "decision-makers" and "stakeholders" exist in applying CoAXs.
Concepción	May, 2018	14	25 (2 work-shops)	Exclusive lanes	Jobs, healthcare facilities, green spaces, educational establishments, supermarkets street markets	Identify impacts on learning about the transport projects; understand CoAXs' potential for facilitating collaboration and planning.
Tshwane	July, 2018	11 (2 work-shops)	20 (2 work-shops)	BRT corridor	Jobs by different sectors	Assess impacts on participants' understanding of the public transport projects, their attitudes about the projects, and their enthusiasm in using or advocating for them.
Bogotá	March, 2019	14	0	Integrating informal buses	Jobs	If accessibility-based analysis could reveal important impacts of integrating informal systems, and potentially help guide the formalization process.

3.1. User Interfaces and Interactivity

The user interfaces and interaction possibilities varied (**Error! Reference source not found.**), based upon data availability, public transport projects included, and context-specific aspects. For Santiago, the seven transport projects were bundled into four different "scenarios;" users could turn off/on the scenarios and examine accessibility to three opportunity types (with health and education opportunities differentiated by official quality "rankings"). For Concepción, users could compare a base and build scenario, and toggle between seven different opportunity types rather than seeing graphs for all of them simultaneously. Tshwane had two hypothetical scenarios for a single corridor: one representing buses in mixed traffic and the other with dedicated lanes. Users could switch between the scenarios and a base (existing) case. Users could also include or exclude up to seven bus feeder routes, important for extending accessibility benefits to communities in Tshwane's low-density settings. Finally, the Conveyal Analysis interface used in Bogotá offers the same core features as CoAXs, but in a less user-friendly format. A large map shows isochrones, a less-aesthetic representation of the transit projects, and a dot layer of opportunities. The number of opportunities accessible from the chosen origin are shown in a probabilistic curve more difficult to interpret than the column charts used in CoAXs. Users could select scenarios and opportunity types, but from a cluttered menu with many options not directly relevant to the workshop.

3.2. Impacts on Participants

Table 4 summarizes comparable survey responses, testing pre-/post-workshop changes within each city. The first four rows, indicating learning about the specific public transportation projects, suggest significant shifts for the cities that included workshops with the general public. For Bogotá, the lack of learning about the projects may have been due to the fact that participants were transit agency officials, who presumably were already familiar with the projects.

Table 4. Comparison of Pre-/Post-Workshop Responses within Each City

	Survey Questions		Santiago	Concepción	Tshwane	Bogotá
Project Learning	I know the projects presented.	Shift	1.20*	0.70*	0.31*	0.35
		p-value	0.002	0.004	0.033	0.143
	I can describe the features of the proposed projects to my friends.	Shift	0.80*	0.57*	0.31*	0.10
		p-value	0.004	0.007	0.033	0.608
	I can describe the impacts of proposed projects to my friends.	Shift	1.47*	0.48*	0.14	0.00
		p-value	0.001	0.015	0.490	1.000
	I have enough knowledge to advocate for/against the proposed projects.	Shift	0.40	0.65*	0.38*	-0.10
		p-value	0.120	0.009	0.024	0.596
Project Enthusiasm	The proposed projects will be effective at improving transportation in the city.	Shift	-0.07	-0.13	-0.25	-0.10
		p-value	0.766	0.427	0.115	0.407
	The proposed projects will help advance important broader urban goals (e.g. housing, education).	Shift	-0.33	0.30^	0.21	-0.05
		p-value	0.220	0.097	0.144	0.780
Concept Learning	Understanding accessibility is key to public policy making.	Shift	-0.13	0.26	-0.14	-0.30*
		p-value	0.424	0.124	0.407	0.020
	Understanding accessibility is key to encouraging discussion around the impact of transportation projects.	Shift	-0.07	-0.13	-0.07	-0.20^
		p-value	0.773	0.492	0.821	0.072
	Number of observations		15	38	31	20

Note: p-value is for the Wilcoxon signed-rank test, a paired difference test. * p<0.05; ^ p<0.10

The two questions gauging enthusiasm for the public transport enhancements aim to test if the tool might enhance stakeholders' willingness to advocate for the enhancements, due to their potential to directly improve transportation conditions and/or urban conditions more generally. The results do not support the hypothesis. In Santiago, the lack of effect regarding "improving transportation in the city" was likely because initial, pre-workshop, agreement with the question was already strong. In Concepción, a marginally significant ($p<0.10$) positive shift was detected regarding broader urban goals. No significant effects were detected for Tshwane or Bogotá.

Finally, in terms of learning about accessibility and its potential value in deliberations and policy-making, we find little supporting evidence. The only significant effects were found for

Bogotá, where transit agency professionals' responses indicated negative shifts in the value of accessibility for policy-making (p=0.02) and encouraging discussion (p=0.07). This may be because the accessibility changes were reasonably modest in the scenarios assessed in Bogotá and/or the fact that time-constrained and cost-constrained accessibility were deemed especially important by the participants.

Table 5. Comparison of Pre-/Post-Workshop Responses between Participant Types

	Survey Statement	Participant type	Pre-workshop	Post-workshop	W p-value
Project Learning	I know the projects presented.	Officials	3.76	4.27	0.00
		Public	3.74	4.39	0.00
		M-W p-value	0.02	0.64	
	I can describe the features of the proposed projects to my friends.	Officials	3.82	4.12	0.04
		Public	3.58	4.13	0.00
		M-W p-value	0.00	0.99	
	I can describe the impacts of proposed projects to my friends.	Officials	3.88	4.16	0.19
		Public	3.45	4.05	0.00
		M-W p-value	0.00	0.40	
	I have enough knowledge to advocate for/against the proposed projects.	Officials	3.96	4.04	0.93
		Public	3.11	3.79	0.00
		M-W p-value	0.00	0.26	
Project Enthusiasm	The proposed projects will be effective at improving transportation in the city.	Officials	4.21	4.18	0.82
		Public	4.29	4.03	0.06
		M-W p-value	0.32	0.98	
	The proposed projects will help advance important broader urban goals (e.g. housing, education).	Officials	3.86	4.00	0.38
		Public	4.03	4.13	0.51
		M-W p-value	0.18	0.10	
Concept Learning	Understanding accessibility is key to public policy making.	Officials	4.46	4.50	0.75
		Public	4.55	4.53	0.84
		M-W p-value	0.39	0.86	
	Understanding accessibility is key to encouraging discussion around the impact of transportation projects.	Officials	4.43	4.46	0.71
		Public	4.68	4.50	0.08
		M-W p-value	0.08	0.92	

Notes: n (officials) = 50; n (public) = 54. M-W: Mann-Whitney; W: Wilcoxon.

A key outcome of a participatory process is achieving, at minimum, a dialogue among different interests, if not mutual learning and, ideally, consensus. Pooling participants from all workshops, Table 5 shows support for learning and knowledge convergence, but only specific to the projects. Pre-workshop, the general public had lower project-specific knowledge than officials; the differences disappeared after the workshops, because the public learned about the projects. Regarding project enthusiasm, however, no significant pre- or post-workshop differences among officials and public users were revealed. A similar lack of differences was found regarding the importance of the accessibility concept; notably, stated beliefs in the importance of the accessibility concept were high in all cases.

A good participation process should also generate greater understanding among participants and empathy for each other and others in the community. Figure 2 shows that, across the cities, the majority of participants did not find CoAXs to be distracting and agreed it provided a “common ground for all participants to work together” and “helped raise important issues for discussions.” The vast majority of respondents provided evidence the process generated empathy, agreeing that it “helped me imagine what commute/travel is like for others.” Responses to some of the other questions also provided nuanced evidence of empathy-building. In Tshwane, for example, 37% of respondents indicated that CoAXs broadened awareness of the impact of the dedicated lane scenario on other neighborhoods. Car users accounted for a disproportionately large share of those shifts, suggesting empathy across heterogeneous stakeholders. Comparing pre-/post-responses between car-users and public transport users shows that the two groups converged in their expected impacts of the dedicated lane scenario on different user groups (i.e., inter-group differences became less significant). Furthermore, a large majority (88%) agreed with the statement “CoAXs helped me imagine what commute/travel is like for others.” A tool like CoAXs may help reduce resistance to public transportation projects which pit local resistors against non-local beneficiaries.

3.3. Additional Observations

While participants in all the cities rated CoAXs positively for usefulness and usability, feedback suggested areas for improvements. In Santiago, participants indicated it would be informative to provide the capability to reverse the accessibility analysis, to quantify potential catchment areas for destinations (e.g., job access to labor). Users in Concepción suggested the need for modeling traffic impacts, similar to suggestions in the Tshwane case, where users noted that comparing travel time savings between car and BRT would have been useful to demonstrate tradeoffs in bus- versus car-based accessibility. Modeling traffic impacts, however, would add considerable complexity since Conveyal Analysis can only generate public transport time estimates. Another suggestion was to show time- and cost-based accessibility measures, due to public transport affordability concerns and the use of distance-based fares in some cases (e.g., Tshwane). Unfortunately, the backend capability to calculate travel cost surfaces was unavailable.

In Concepción and Tshwane users had different ability and/or willingness to engage with CoAXs and, arguably, the participatory process. In Concepción, most of the participating officials were more forthcoming in discussions (expressing three times as many opinions per participant than public transportation users). Older participants, who also had lower levels of education, required roughly twice as much introductory guidance before interacting with CoAXs. Once they did engage, however, they demonstrated an intuitive understanding of accessibility by, for example, suggesting that adding destinations on the city’s outskirts might be better than improving train frequency. Overall, none of the workshop contexts has a deep culture of participation in public transport projects, which certainly affected the workshops’ outcomes.

3.4. Limitations

Attempts to compare participatory processes and generalize from them face numerous challenges. Many aspects varied across the contexts, so the workshop experiences should be viewed as demonstrations of the potentials to deploy and evaluate such technology in public processes. Each specific case varied in terms of the status of the transportation projects included and subsequent sensitivities. The relationships between the research team and the local communities also varied, which impacted, for example, participation. In Concepción, strong contacts and previous relationships with local officials and residents in specific communities helped secure their participation. In Tshwane, on the other hand, despite reaching out to nearly 7,000 people through local political networks, only 11 people thusly contacted attended the first two workshops. The Bogotá case did not include a workshop with the public because transit agency officials were concerned about complicating an already politically complex process of trying to formalize the semi-formal transit routes and integrate them with the rest of the system. The Bogotá case highlights differences in the "position" of the projects within their respective planning processes. In Tshwane, for example, the projects were somewhat more locally specific and controversial, with workshop participants from directly impacted neighborhoods. They already viewed the project as too advanced by authorities for any input to be meaningful, which has been shown elsewhere to disenfranchise stakeholders (16).

Regarding assessment, an important limitation of the experimental design was the lack of a control group. Some of the changes detected, such as learning about the projects, could simply have been a function of discussing the projects themselves, irrespective of the tool. In addition, our samples were small and non-representative, since we carried out the workshops on limited budgets, aimed to ensure a quality experience for participants, and faced some challenges in recruiting participants. Significant or insignificant results may be spurious and are not generalizable

4. SCALING UP?

The workshop contexts differed in institutional capacity for public engagement and data and technical capacity for using a tool like CoAXs. The Chilean cities had GTFS data readily available; Tshwane and Bogotá did not. Data on opportunities were available, but through personal contacts with relevant sources. Many of the world's cities share similarities with those where CoAXs has been tested and nearly all of them need public transportation improvements and meaningful public engagement. Can CoAXs be scaled to serve a planet of cities?

4.1. Technical and Licensing Considerations

CoAXs is developed in JavaScript, the most common programming language, and builds upon Conveyal Analysis, a leading FOSS application for public transport accessibility analysis. Nonetheless, using Analysis has costs, such as for Amazon Web Services. Deploying it requires technical skills, labor and persistence. Users could pay Conveyal for Analysis and technical support, but such costs might inhibit widespread use in resource-constrained contexts. These pose barriers to CoAXs users, especially those who would not also use Analysis for internal planning.

CoAXs is browser-based to ensure compatibility across operating systems and devices. A common risk of browser-based FOSS projects is that server costs increase with popularity. To avoid this, developers push computation and data storage onto the client, rather than server, side. While CoAXs inherently depends on the server-side calculations of Analysis, it pushes visualization computation to the client-side. As a result, we were able to host CoAXs for free on heroku.com in Concepción and Tshwane.

To serve particular contexts and projects, CoAXs must be customizable, but modifications require programming skills. Taking full advantage of modularized code and enabling customization by non-technical planners could drastically enhance CoAXs' scalability. Nonetheless, even if CoAXs were developed to enable code-free customization, building an active community of contributors and users can be just as important and challenging as developing the FOSS itself (38). Due to CoAXs' inextricable dependency on Analysis, Conveyal is an obvious candidate to lead the community of developers and ensure CoAXs remains compatible. As a private company, though, Conveyal would likely require financial support for such a role.

An appropriate license can help ensure a tool like CoAXs remains FOSS. Permissive licenses require attribution and liberate the original authors from liability. Copyleft licenses, such as the GNU General Public License (GPL), ensure attribution and liability protection for authors and mandate that derivatives use a copyleft license. CoAXs was originally developed under the permissive Apache 2.0 license, but switching to a copyleft license designed for browser-based applications may help CoAXs attract the community of developers needed to scale. If Conveyal were to manage CoAXs, it might consider a BSD license to add brand protection (39).

4.2. Institutional Considerations

Successful FOSS requires more than coding and licensing considerations. For example, the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) established the Open Data for Resilience Initiative which created GeoNode, a web catalog allowing users to share, access and visualize geospatial data. An assessment of GeoNode emphasized that purposeful collaboration-related practices for vendors and users – such as communications, engagement, collaboration infrastructure, user experience – were critical (40). After about $1-1.5 million in investment over seven years, GeoNode is currently used and maintained by "hundreds of organizations — governmental, non-profit, and commercial" and thus seems to be an example of FOSS "success" (40).

A more specialized tool like CoAXs may face more challenges in scaling. Other entities will only lead their own implementations if CoAXs is thoroughly documented, with updates and bug fixes released in a timely manner. A release team, with a diverse composition, can play an important role, to help "developers reach technical consensus through influence rather than direct control" (41). A community maintaining a tool like CoAXs should include representation from different countries and sectors and follow emerging knowledge about the relationship between FOSS and open source development ecosystems (42). That said, since CoAXs serves a niche market, it may not many volunteer contributors. CoAXs or similar tools would most efficiently be maintained by for-profit companies such as Conveyal or Remix, that maintain accessibility analysis tools for analysts. These companies could easily maintain a minimalist, customizable interface for their tools for use in public engagement workshops.

4.3. Scaling CoAXs as a Participatory FOSS

The following summarizes CoAXs' current compliance with best practices for scaling FOSS:

1. Popular programming languages: Yes – Javascript is most popular
2. Interoperability with exiting, popular software: Yes – uses Conveyal Analysis back end
3. Cross-platform compatibility: Yes – browser-based

4. Avoid server costs: Some computation pushed to client side
5. Use appropriate license: No – should use copyleft
6. Streamline deployment: Dockerized, but use requires coding
7. Thorough documentation: No – insufficient for third party adoption
8. Diverse release team: No – current developers MIT-based.

Ultimately, even if CoAXs were to scale as a successful FOSS which local governments can customize and deploy, it may then create a situation where agencies focus too heavily on the tool without providing other elements necessary for effective public engagement. Relevant documentation should emphasize CoAXs' role as just one part of a more holistic public engagement process, designed with a deep understanding of the political economy and technical capacities. Ideally, such deployments could also build on the experimental foundations established in this paper, to continue growing the empirical evidence of its usability, usefulness, and impacts.

5. CONCLUSIONS

This paper assessed the impacts of, and potentials for, deploying an ABVT designed to enhance public engagement in public transportation planning. We deployed the tool in workshops in four cities from three countries from the Global South; these contexts represented medium to large cities, from countries with relatively high levels of human development, high income inequality, and varying measures of democracy, and somewhat distinct cultures and levels of technical capabilities. The workshops revealed consistent evidence that participants' knowledge about the projects improved and converged. Interestingly, in this respect, the public, as opposed to officials, shifted in project learning, which supports the value of the tool for public engagement. Little evidence emerged, however, regarding impacts on enthusiasm for the projects assessed or learning about the concept of accessibility. Participants did agree on the usefulness and usability of the tool and its effectiveness in promoting dialogue and empathy. Although the workshops indicate some relevance of the approach across different cultures and settings, they also revealed evidence of digital and participatory divides.

The workshop outcomes should be viewed as indicative and not generalizable, due to the small number of participants, the lack of control groups, and considerable variation in the experiences across the cities. The results suggest such tools can enhance public transportation planning processes, globally. Still, "scaling up" the technology would require an active community of contributors and users and presents institutional, documentation, and licensing implications. Broadening the use of such tools would also require evidence that they can be "scaled up" within actual participatory processes – beyond the small set of experimental workshops presented here. Ultimately, meaningful participation requires broad representation and open opportunities from the earliest stages of planning. In the face of limited time and resources, scaling that dimension requires overcoming institutional, technical, and procedural challenges.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: Study conception and design: CZ, CV, CN, JAC, JL, EV-T; data collection: JL, CZ, JAC, CN, CV, EV-T; analysis and interpretation of results: JL, CZ; draft manuscript preparation: CZ, JL. All authors reviewed the results and approved the final version of the manuscript. The authors do not have any conflicts of interest to declare.

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Figure 1. Examples of User Interfaces in Each Case (clockwise from top left: Santiago, Concepción, Tshwane, Bogotá)

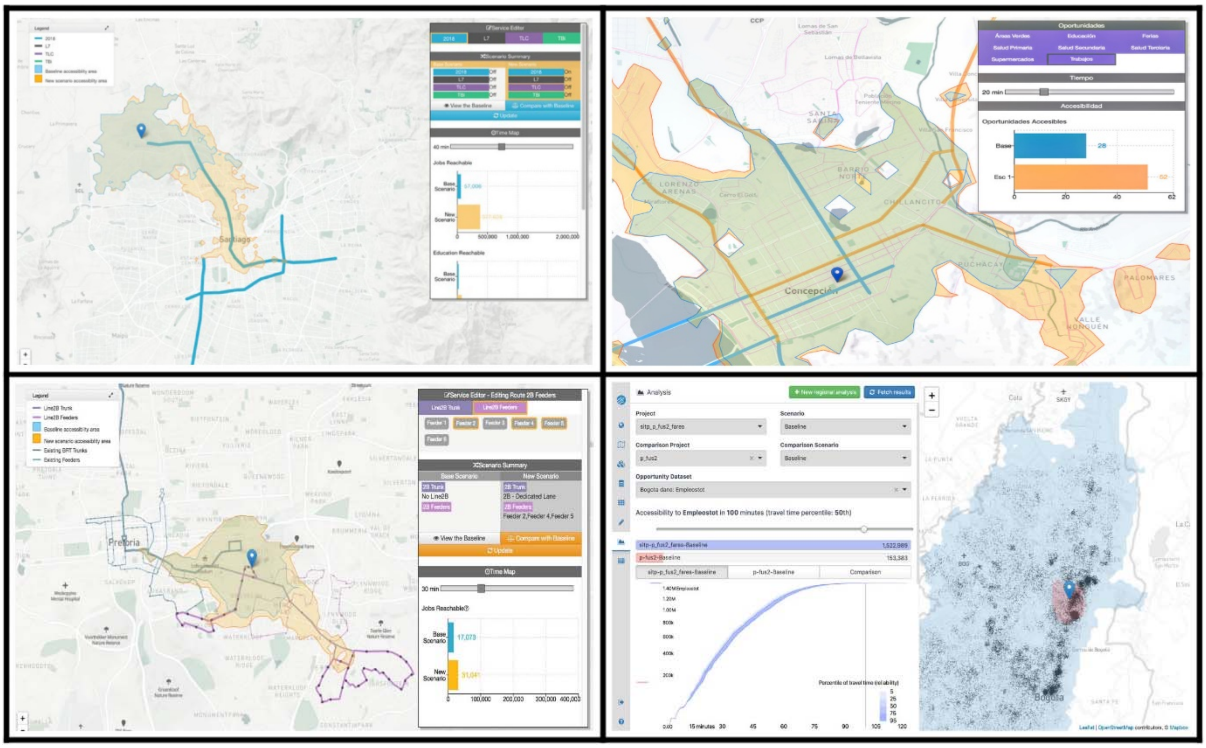

Figure 2. Indicators of CoAXs' Reported Usefulness as an Engagement Tool (Y axis is percentage of respondents in each city agreeing with the Likert-scale answer)