Co-producing space-time accessibility: a transdisciplinary approach to enhancing transportation justice.

Abstract

Accessibility analysis has long been used to gauge inequalities and inequities in people's ability to reach employment, education, greenspaces, and other activity locations. This paper proposes that the contributions that accessibility analysis makes to addressing transportation justice can be enhanced if the knowledge production processes that generate accessibility outcomes are adapted. It therefore introduces a transdisciplinary approach to co-produced space-time accessibility measurement, CoProSTAM, in which experiential, practitioner and academics knowers collaborate closely. CoProSTAM has been developed on the basis of our collaboration between academic researchers, a collective of low-income women (Dimú), and local policymakers in the Medellin metropolitan area in Colombia. The paper also presents an empirical application which shows how accessibility varies according to the location of publicly available childcare facilities, with profound implications for the livelihoods and opportunities for healthy living among low-income women in the Global South. By building on our CoProSTAM approach, accessibility researchers will be able reduce the epistemic injustices that are embedded in much transport research and foster new ways of understanding inequalities in accessibility in and around urban areas.

Keywords: *transportation justice, epistemic justice, accessibility analysis, space-time accessibility, coproduction, gender, Colombia*.

1 Introduction

In transport and urban research, accessibility has long been used to gauge transportation inequity and injustice in the employment, education, health, greenspace and other opportunities that individuals and communities can reach, given the distribution of land uses and configuration of transport systems (Martens, 2012; Pereira et al., 2017; Willberg et al., 2024). A suite of different accessibility measures has been deployed to this effect, from place-based measures such as the distance to the nearest opportunity, cumulative opportunity measures, gravity-based measures and floating catchment area measures (e.g. Klar et al., 2023; Pirie, 1979; Wan et al., 2012). While useful, the use of these measures has been criticized for failing to capture many interpersonal differences in time availability, access to particular means of transport, or cultural norms and values that assign particular responsibilities and roles to specific individuals (e.g. Chen & Yeh, 2021; Kwan, 1998; Neutens et al., 2010; Schwanen & de Jong, 2008). Mei-Po Kwan, for instance, has argued for the use of space-time accessibility measures (STAMs), on the grounds that these can better articulate how accessibility is shaped by the gendered nature of activity and travel patterns (Kwan, 1998; Kwan & Weber, 2008).

STAMs have seen significant advancement since they were first proposed by the Lund School around Torsten Hägerstrand in the 1970s (Hägerstrand, Torsten, 1970; Lenntorp, Bo., 1976). The use of GIS and geo-computation has allowed, among others, the incorporation of the consequences of road congestion on travel speeds (Wu et al., 2001), the existence of multimodal transport network (Qin & Liao, 2024), variations in opening hours of facilities at destinations (Kim & Kwan, 2003), uncertainty over travel times and the start and end times of time windows within which flexible activities and travel can be undertaken (Ettema & Timmermans, 2007; Fu et al., 2022; Kuijpers et al., 2010; Lee & Miller, 2020), and the existence of monetary and carbon budgets alongside spatial and temporal constraints (Mahmoudi et al., 2019; Qin & Liao, 2024). All these improvements can be harnessed in the evaluation of transportation inequity and injustice.

Yet, studies employing STAMs can make additional contributions to transportation justice if its processes and practices are changed such that it contributes to greater epistemic justice – how knowledge production is attuned to the experiences and knowledge of diverse groups and individuals. Epistemic justice is attracting increasing attention in transport and mobility research (Lindberg et al., 2023; Lowe et al., 2023; Schwanen, 2021; Smeds et al., 2020) but the term has multiple meanings and dimensions. A first dimension is about inclusion, and the question of equitable participation of different (groups of) knowers in knowledge production (Pohlhaus, 2017). Key concerns here relate to testimonial injustice and testimonial smothering (Dotson, 2012; Fricker, 2007). The former relates to particular knowers not being given the opportunity to make their voice heard, and the latter that knowers may abridge or otherwise leave out important elements from what they communicate because they believe others are more interested or may not want to hear those elements. A second dimension refers to hermeneutical injustice (Fricker, 2007; Pohlhaus, 2017), which arises when epistemic resources – e.g., conceptual frameworks, models and methodological practices – cannot

adequately respond to the understandings, practices and experiences shared by certain knowers because those resources are inadequately developed. Nested within the broader category of hermeneutical injustice is 'wilful hermeneutical ignorance', which arises when researchers keep using frameworks or models that are inapt for understanding and responding to particular practices and experiences (Pohlhaus, 2017).

The aim of this paper is to introduce a transdisciplinary approach to space-time accessibility measurement that recognises unevenly structured power relations within knowledge co-production and prioritises epistemic justice in accessibility analysis. Demonstrating how greater epistemic justice can be realised within an actual research project using STAM together with a group of marginalised individuals is an integral part of what the paper tries to achieve. We, therefore, discuss a co-produced STAM – henceforth called CoProSTAM – that was developed between academic researchers, local authorities in Itagüí – a municipality in the Medellin metropolitan area, Colombia – and a collective of low-income women living in a semi-formal and peripheral development in Itagüí. The experimental process we followed was far from perfect – and significantly affected by the COVID-19 pandemic. Nonetheless, it offers a rich account of how collaboration and continual dialogue among academic knowers, practitioner knowers (local authority representatives), and experiential knowers (low-income women) shaped the various decisions involved in designing CoProSTAM as well as the modelling results and interpretation.

We consider it important that the structure of the paper aligns with the processes through which CoProSTAM was specified and applied. This is why the remainder of the paper commences with a brief introduction to the group of experiential knowers with whom CoProSTAM was developed. Offering an early description of this group of co-researchers and the ways they interacted with the academic and practitioner knowers sets the scene for understanding how the logics of academic, practitioner, and experiential knowers intertwine to produce CoProSTAM. This is followed by a presentation of the general approach underpinning CoProSTAM, with special attention directed to the methods for creating an accessibility measure centres epistemic justice. We subsequently offer an account of how CoProSTAM was used to consider a practical accessibility problem that the participating low-income women agreed mattered significantly to their daily lives. The paper concludes with reflections on how transdisciplinary coproduced STAM analysis can be advanced in the future.

2 Context: Dimú

During January 2020 women in charge of at least one child of 8 years of age or less and living in the peri-urban area of Itagüí known as the Corregimiento (Figure 1) were invited to take part in a two-day workshop to discuss their access to healthy living. Invitations were distributed by academics in [redacted for peer reviewed purposes] through local schools and day-care centres in the areas of interest, and local community leaders contacted in person. The workshop included lunch and coffee, and childcare was provided during the activities. The workshop was held at one of the biggest childcare centres in the area to offer a space that

would be easy to access and feel familiar, safe, and neutral for the participating women. The equivalent of the national minimum hourly salary plus a transport subsidy were offered to all attendees. As a result of this workshop, a civil society collective was created and named "Dimú – diálogo con mujeres emprendedoras" (dialogue with entrepreneurial women).

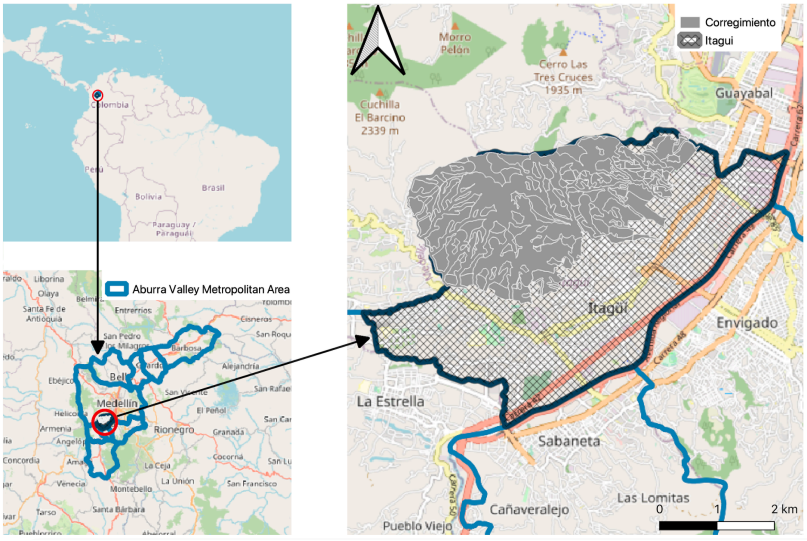


Figure 1. Map of the location of the Corregimiento in Itagüí, municipality part of Medellin's metropolitan area.

Dimú consists of around 40 women most of which have been part of the group since the first workshop. In 2020 their median individual monthly income was US$ 13-30 and that of their household US$ 135-270, both of which are significantly below the average for the Medellin metropolitan region (**Table 1**). Although Dimú membership and level of participation has varied, our most recent survey indicated that only 4 members were employed, 13 worked as independents, 12 were unemployed and 9 were full-time homemakers (Orjuela & Schwanen, 2023). The Corregimiento is a peripheral and starkly marginalised area within the municipality of Itagüí and the wider metropolitan area. A shortage of local jobs and services is compounded by geographical barriers such as its high-slope mountains and the Medellin River to the East of Itagüí.

Table 1. Demographic data of Dimú members and averages for the Medellin Metropolitan Area*

		Min	Median	Mode	Max
Age	Dimú	21	32	32	67
Monthly income**	Dimú (individuals)	0	US$ 13.5-<27	US$ 27-<135	US$ 135-<270
	Dimú (total per household)	0	US$ 135-< 270	US$ 135-< 270	US$ 270-<540
	Medellin Met Area (mean for economically active population)			314	
		Employed	**Unemployed**	**Not looking for a job**	**Other**

Employment status	Dimú	42.5%	30.0%	22.5%	5.0%
	Medellin Met Area	47.7%	6.3%	46.0%	-

*Numbers for the Medellin Metropolitan Area are estimated using the official data found at (González et al., 2023; Pulgarín Agudelo & Torres Gómez, 2022)
**Income values are estimates in USD in 2020 based on surveys done in Colombian Pesos (COP)

Knowledge exchange processes started with two workshops in early 2020, in which, on the insistence of the Dimú members, representatives of Itagüí's local government secretariats of health, mobility, and environment also took part. When the COVID-19 pandemic hit, all in-person activities were suspended. Between April and September 2020, this knowledge exchange took place through a combination of WhatsApp-based story-telling exercises and surveys, which included contributions through videos, photographs, voice messages, personal diaries, and crafts. After the lockdown, we carried out a set of activities we have called 'experiential focus groups' where Dimú members would choose a set of places to be visited and route to be followed to reflect on specific topics part of our research. Note that these experiential focus groups are neither traditional walkalongs as they are not ethnographic research, nor an observation of movement from participants. We believe this to be a different type of method to those defined by Urry (2007) in the set of tools available for mobilities research. In short, Dimú members were given as much freedom as possible to choose how they wanted to share their views and concerns.

Accessibility and healthy living were the most important topics at the centre of knowledge exchange activities with Dimú. Accessibility to the city's goods and services in general was emphasized to be limited by lack of amenities close to their place of residence, safe walking routes at night, and very limited modal choice that restricted most of their trips to walking. None of the Dimú members had regular access to a car, and only a few of them have sometimes access to an acquaintance's motorcycle. Active travel other than walking is impeded by the high-slope hills where they live which make cycling and other active travel alternatives an impossibility. Taxis and ride hailing are too expensive for daily trips and unavailable at night because drivers refuse to take trips to/from the Corregimiento after dark because of safety concerns. Public transport is offered but the buses used by the local authority are too big for the narrow infrastructure in the area, making the schedule times infrequent and unreliable. The women in Dimú also perceived public bus use as unviable when carrying bags or babies, as they cannot go through the turnstiles with them. Access to places for a healthy living was extensively discussed during the workshops.

It is in this context that we created CoProSTAM, an accessibility measure that would be academically robust, enhances epistemic justice through recognition of the accessibility barriers experienced by Dimú, and that would offer useful insights for those involved in transport, health, and environmental policymaking in the area. It was collectively agreed among the three groups of knowers that the accessibility measure would centre access to 'healthy living', defined by four distinct components: i.) mental health, spirituality, and entertainment; ii.) health

services; iii.) green areas, leisure, physical activity, parks, and environment; and iv.) home and food.

3 General approach

In this section we present a detailed description of the transdisciplinary methodology developed for CoProSTAM in general terms. This section presents the steps taken to create a transdisciplinary approach to space-time accessibility measurement that centres knowledge co-production in a reflexive manner aware of forms of knowledge beyond the academic one. CoProSTAM's development is premised on two sets of guiding principles and follows a sequence of three practical stages. The guiding principles are elaborated in sub-section 3.1. The sequence of practical stages can be summarized as early definitions, iterative process, and results and final products and these are elaborated in the sub-sections that follow.

3.1 Guiding principles

The first set of guiding principles, namely pragmatism and flexibility, sought to minimize hermeneutical injustice and maximize applicability of the developed tool. While the technical proficiency of STAM analysis has improved markedly over the past two decades, CoProSTAM is based on an algorithm that is straightforward and can be implemented with readily available open-source software. This means that it can easily be embedded within the planning and policy formation processes of public authorities with modest resources and geo-computational competencies. Moreover, the steps taken in the computational process and kinds of data inputs required can be communicated with, and understood by, individuals with no prior training in either geo-computation or accessibility analysis. This approach made it possible for Dimú members and other non-academic knowers (see below) to contribute to, and challenge, the steps and decision-making in CoProSTAM analysis.

The second set of guiding principles – plurality, continuity, and legitimacy of voice – emerged from some simple 'rules of the game' for interaction that the academic knowers developed a priori. The eventual guiding principles informed the whole CoProSTAM development process. They sought to reduce the risks of testimonial injustice and testimonial smothering, and help generate an atmosphere in which the status quo in the lives and mobility experiences of women like those in Dimú could be challenged openly and safely.

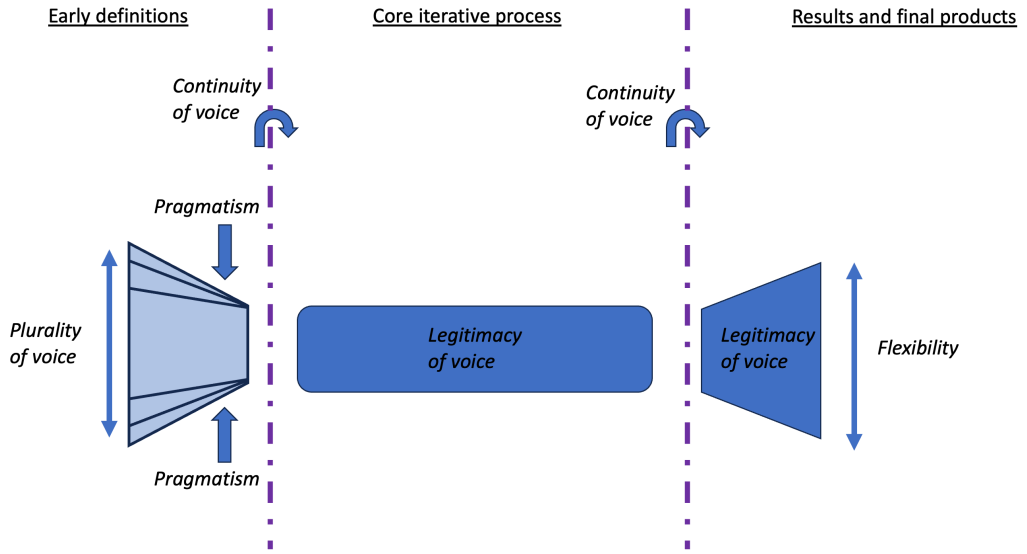
Plurality of voice: The potential of CoProSTAM to include knowers that have been traditionally excluded from this process depends on its ability to congregate plural voices as means for testimonial justice. Here, by 'plurality' we mean voices that can represent various knowledges inside and outside of traditional epistemic institutions. This does not go against focusing on specific ethnicities or demographics. For example, in our case, we have worked with a group that accepts

('only') women[1] with very low incomes and whose experiential knowledges have been systematically excluded from knowledge production processes institutionalised in the realms of academia and public planning.

Continuity of voice: One way to reduce testimonial smothering is to create spaces where trust and detailed exploration are fostered. The continuity of voice, that is, the understanding that the voices co-producing the accessibility measure will do so throughout the various stages of the process, is essential in this aspect. The continuity of voice is therefore a key distinction between co-production processes and consultation exercises which have larger risks of being exploitative and leave more room for interpretation from some power-rich knowers.

Legitimacy of voice: this is the recognition of the legitimate concerns, suggestions, and analyses of the various voices involved. It allows for the creation of knowledge production processes which avoid the dismissal of matters raised by some knowers and the invalidation of some epistemologies. It is important to highlight that recognising the legitimacy of voices does not imply an agreement or consensus to take decisions. In our work we constantly reached points where we had to prioritise financial, temporal, and human resources, recognising some concerns would have to be left for future work or were against the principles of pragmatism explained before. However, all concerns were noted and through meetings and workshops, major concerns were addressed collectively.

With these guiding principles defined, we move towards the practical stages of the process. Figure 2 shows how these stages of early definitions, core iterative process, and results and final products intersect with guiding principles of pragmatism, flexibility, and the three principles of inclusive participation.



[1] Although transgender women were welcome to join the group, all participants identified themselves as cisgender women. Despite posters, participant information sheets and other announcements to take part said explicitly the call was for women only, one man came to the first workshop and was turned down by workshop organisers. No non-binary people showed explicit interest in joining.

Figure 2. General approach divided in three practical stages (early definitions, core iterative process, and results and final products) and their relationship with guiding principles.

3.2 Early definitions

In the first stage we defined the groups that would contribute to the project, the specific research questions, and the structures for operationalising and using Co-ProSTAM. To explicitly recognise the various types of knowledges while providing a clear structure for the operationalisation and analysis process, we created three categories of knowers – experiential, academic, and practitioner.

Experiential knowers are people who experience the accessibility, poverty, and gender discrimination conditions part of this research (Gélineau et al., 2024; Wresinski, 2005). These are, in turn, those who are better equipped to choose what elements of daily experiences need to be included and to judge if the abstract representations in a mathematical model are relevant for the experience of the issues they intend to address. This group of knowers will define the various components of accessibility, will define activity diaries and priorities, and provide advice on outputs to share with different audiences (Table 2).

Practitioner knowers are those who know the issues at hand through daily professional activities such as policy makers and civil servants (Gélineau et al., 2024; Wresinski, 2005). These are knowers in the action part of PAR, and the various trade-offs, compromises, and restrictions associated to it. In the words of Wresinski (2005), "academic studies cannot replace the knowledge that the action can and should have of itself, for itself" (Wresinski, 2005, page 8). In geographical contexts like Itagüí where the resources and capabilities available to public authorities are severely restricted and staff need to juggle multiple resources and/or move quickly between roles, many officials may not have work for long periods of times on a specific topic or in a given role. However, support from high-ranking officials may help to offer greater continuity in a professional organisation and will typically be able to communicate the organisation's needs to more junior colleagues. Furthermore, the group of practitioner knowers should offer an opportunity for horizontal integration (i.e. between various administrative offices related to transport, land use, and environment) and vertical integration (i.e. between various government scales like local, regional, and national).

Academic knowers are scientists, scholars, and university students whose research practices are – or at least should be – informed by the rules, norms and procedures defined by the academic research communities to which they belong. Academic knowers are in charge of creating algorithms, defining the data needs for the model to work, and adjust it to better reflect the experiences of the experiential knowers. They are also in charge of coordinating and managing the entire process. This group should be able to combine skills associated to quantitative methods of accessibility modelling and statistics, ethnographic studies, time geography, and policy scenarios.

The combination of these three groups creates a research structure that redistributes expertise (Whatmore & Landström, 2011) while facilitating the evaluation of (realised changes in) testimonial justice in that process (Gélineau et al., 2024). Note that the three groups categories need not be mutually exclusive as some individuals may be part of more than one category (e.g., an academic researcher who

also works for local government) or switch between categories across different stages in the operationalisation and analysis process (e.g. an experiential knower who, possibly because of participation in the research, decides to apply for a local government position).

Table 2. Defined responsibilities for the three groups of knowers.

Knower type	Brief description of the group	Main responsibilities
Academic	Knowers within academic structures.	Funding, CoProSTAM coding, survey design and deployment, workshop design and organisation, manage and coordinate the project, lead academic outputs such as papers.
Experiential	Knowers living in the area of interest with daily experiences of the accessibility and mobility aspects at hand.	Define places to measure access to, prioritise components of accessibility, define activity diaries, define time variables. Offer input throughout the process. Help to define main outputs and project legacy.
Practitioners	Knowers from existing governmental structures with access to secondary data on mobility and other areas of interests defined by experiential knowers.	Help build modelling scenarios, provide policy documentation and context, provide secondary data and GIS layers. Help define main outputs and project legacy.

3.3 Core iterative process

The core of the accessibility analysis is an iterative process in which experiential and academic knowers are working towards reaching a model that is practically executable (pragmatism principle), but a fair representation of the main obstacles to accessibility experienced by experiential knowers (legitimacy of voice principle). For the development of CoProSTAM we follow a process like the one described by Kim and Kwan (2003), with some modifications, as shown in **Figure 3**. Below we explain each step and highlight what the co-production aspect of our work adds to traditional conceptions of STAMs.

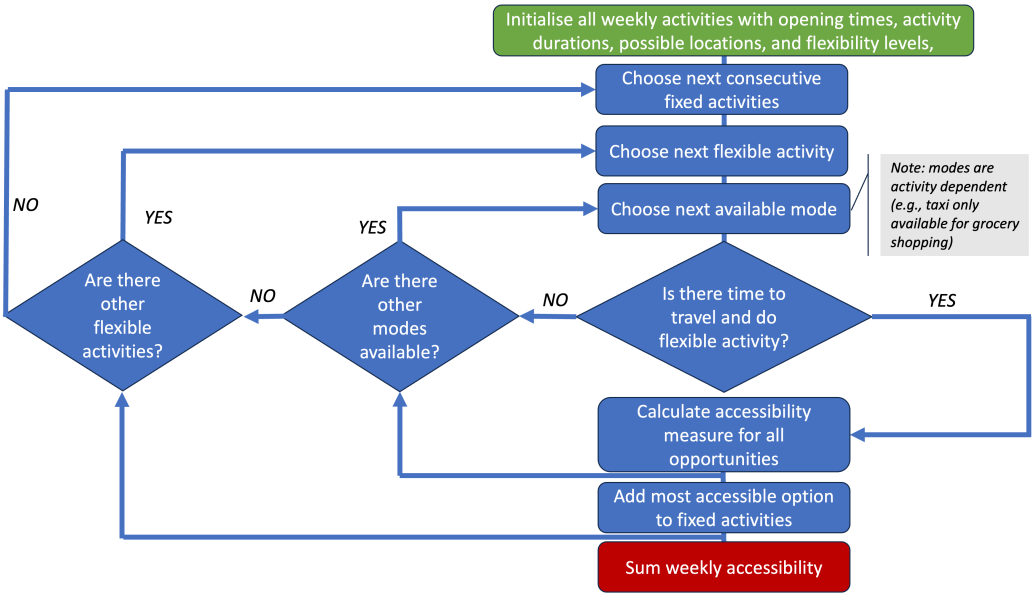


Figure 3. Algorithm followed in CoProSTAM.

3.3.1 Activity programmes and flexibility

STAMs usually begin with the definition of activities included in the activity programme – the list of activities to be conducted in a given time period – as fixed in both space and time, or flexible. Traditional STAMs work by anchoring two fixed locations (typically residence and primary work location) and defining a space of possible opportunities for the flexible ones, which in turn will be used for the accessibility measure. The more opportunities for flexible activities, the larger the accessibility measure. A traditional example can be going grocery shopping (flexible) between work (fixed) and home (fixed). However, as discussed below, the experiential knowers challenged conventional assumptions about space-time fixity and flexibility in STAMs and CoProSTAM treats space-time fixity and flexibility differently compared to other measures.

In this context, fixity and flexibility refer to the ease with which the location of the activity in physical space and/or in a person's day or week can be changed (M. Kwan, 2000). Like Schwanen et al. (2008) who use a fixity/flexibility continuum, we opted for a distinction of fixed versus non-fixed activities with highly fixed activities being only those characterised by a location and start and end times that could not be negotiated. An example of this can be making lunch for one's family. The location is fixed as lunch will be prepared and consumed at home, and the time is also fixed as other family members rely on its availability at specific times.

However, flexible activities come in multiple forms and, informed by the inputs from the Dimú experiential knowers, three activity flexibility dimensions have been defined: engagement, temporal, and spatial flexibilities. The first dimension refers to how important it is for the activity to occur or not. For example, for people working in multi-level marketing or delivering and selling homemade cakes and pastries, visiting clients is very important, especially if livelihoods depend on it, which means this activity will have a low engagement flexibility (i.e. non-negotiable). However, delivering these to clients has some level of spatial and temporal flexibility as they can negotiate when and where to meet. On the other hand, going to church won't happen every day and sometimes not even every week (high engagement flexibility; negotiable) even if it is fixed in both space (their preferred temple) and time (when Mass is held). Some other examples of how these variables are combined in different activities mentioned by Dimú members are shown in **Figure 4**. For example, visiting a family member with reduced mobility may have a large degree of temporal flexibility as the precise moment on when to meet can be discussed and rearranged, but it will have very little spatial flexibility as it is assumed this visit will happen at their home. In contrast, helping kids with their homework may have a large level of spatial flexibility as this can happen at home, at a friend's home, or even out in a park, but its temporal flexibility is quite restricted as the activity will have to take place sometime after school and before bedtime on specific weekdays.

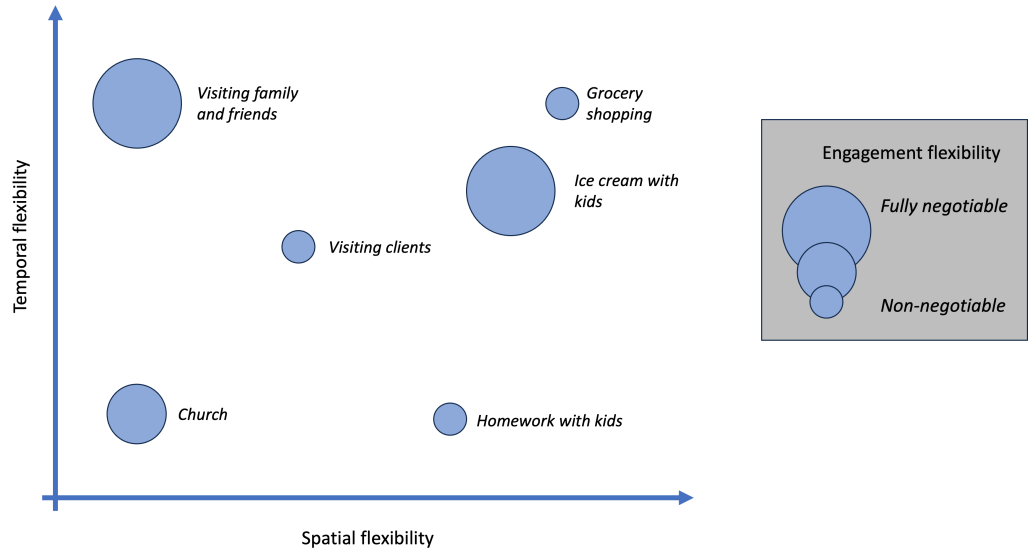


Figure 4. Varying dimensions of activity flexibility used in CoProSTAM.

Experiential knowers are best equipped to define which activities should be included in activity programmes, and the status of those activities as fixed or flexible, as it is their daily activities that are under consideration here. This can be done through travel surveys that are then discussed with academic knowers who will be translating survey answers into model inputs. The surveys and follow-up discussions can also be used to define sources of information for locations and opening times for activities. For example, the exact location and opening times of grocery shops, parks, and other common locations can be defined based on OpenStreetMap (OSM, 2015) and locations and available hours for clients, family and friend visits based on agreed approximations with experiential knowers. Handing over the power to identify these elements reduces the risk of wilful hermeneutical ignorance (Pohlhaus, 2017), discussed in the Introduction section. This risk materialises, for instance, when researchers persist with the assumption that all paid work activities are fixed in space and time, even if they know this may not apply to certain people whose accessibility is being modelled.

A final point on activity programmes is on the priority order the algorithm uses to decide which activity takes place next. Like other STAMs, CoProSTAM assigns fixed activities as a starting point. The order in which CoProSTAM will then look for opportunities to allocate other activities is defined by the order in which these are fed in the activity diary, hence those with lower engagement flexibility (non-negotiable) need to be listed first. This means that the algorithm will look for ways to carry out non-negotiable activities first and opportunities for fully negotiable activities will only be searched for when either no other non-negotiable activities are left, or when spatial and temporal constraints don't allow for those to be done. Take for example visiting a client and going for ice cream. If visiting a client has lower engagement flexibility than going for ice cream, it should be listed in the activity diary first so that the algorithm prioritises opportunity searches to visit clients. However, if there is an available slot at 18:00 for a

flexible activity but no client can be visited after 17:00, the algorithm will look for opportunities for ice cream, even if not all clients have been visited. For activity diaries that span multiple days, activities that cannot be carried out on one day are carried over to the next without further changes in their flexibility definitions. Note how a co-produced approach allows for all the nuance in the definition of fixed and flexible activities mentioned here. For example, activities associated to going to a park can be restricted to occur between sunrise and sunset even if the park is not officially closed if experiential knowers highlight visiting a park after dark being too dangerous to be a real option. Activity schedules get more complex as more elements of daily life are introduced, and hence the flexibility and pragmatic guiding principles are essential in defining a boundary of how complex this process will get, while the participatory principles will guide a minimum level of representation of legitimate concerns. In any case, defining activities in co-production with experiential knowers is both challenging and essential to uncover restrictions in both time and space that people may be subject to that traditional accessibility models typically ignore.

3.3.2 Available modes

After creating the activity schedule, we choose two fixed locations and find which of the flexible activities in the activity programme can be completed in-between, just as other STAMs do. To do this, CoProSTAM needs to define travel modes that are available, which in many cases will mean actively engaging with popular transport (also known as informal or paratransit). Other restrictions such as defining the price level at which taxis and ride hailing become prohibitively expensive, or unofficial operating times due to safety concerns are all part of the richness that comes from co-production with experiential knowers. These transport restrictions and alternatives are typically not mapped or kept in official databases, while routes can be difficult to trace, requiring essential input from experiential knowers. This is why none of these elements have been considered in traditional STAMs.

3.3.3 Calculating accessibility

At the core of accessibility measures there is a mathematical expression that expresses accessibility from an origin as a function of opportunities available at possible destinations and one or more indicators of travel to destinations, usually some version of invested time and/or money (Hanson & Schwab, 1987). STAMs tend to offer a daily accessibility measure. However, the definition of a weekly accessibility measure offers the possibility to include activities with less-than-daily frequency such as visiting friends and family or going to church. Considering the components of healthy living (mental health, health services, green spaces and leisure, and home and food), and how they interact with each other, a weekly definition helps give further flexibility to the model without a big cost on pragmatism. By making relevant activities outside of the “typical” day it may also reduce the risk of testimonial smothering. Considering this, CoProSTAM defines a weekly accessibility measure as the sum of accessibility for daily activities:

$$W_{acc}^{k} = \sum_{k=1}^{max.7} D_{acc} = \sum_{k=1}^{max.7} \sum_{n} Acc_n(v_1, v_2, \cdots, v_i)$$

[equation 1]

Where W^k_{acc} (weekly accessibility) is the sum of the *k* daily accessibilities (D_{acc}). Note that the possibility of weekly timescales and accessibilities does not avoid daily calculations, but just give the possibility of periods that extend beyond one day. This is also why the sum term for *k* is defined as a maximum of seven days. As shown below, *k* can be simplified to, for example, three days to include two weekdays and one Sunday. As the last segment of equation 1 shows, D_{acc} is the sum of accessibility measures for *n* potential path areas (PPA). Every PPA is defined as a geospatial area where flexible activities can take place, limited by the time available between two fixed activities (Kim & Kwan, 2003). For example, if a fixed activity is leaving work at 17:00 and the next fixed activity is being home for dinner at 19:00, the two hours between 17:00 and 19:00 create one PPA delimited by the area that can be visited in those two hours. If the flexible activity is exercising, and the minimum engagement time of this activity is 45 minutes, all fitness centres within 1 hour and 15 minutes of total travel time (i.e. the sum of the time to get there from fixed work and the time to get home after), and with opening times during this window will be part of the opportunity space. Each fitness centre will be a different location *j* for which the accessibility value can be calculated separately. The accessibility in each PPA *n* is defined as:

$$Acc_n(v_1, v_2, \cdots, v_i) = \sum_{j} Dur_j \cdot e^{-(\beta_1 \cdot v_{1,j} + \beta_2 \cdot v_{2,j} + \cdots + \beta_i \cdot v_{i,j})}$$

[equation 2]

Where Acc_n equals the accessibility in the nth PPA, $v_{i,j}$ are the travel resistance variables for location j, Dur_j is the maximum time of engagement in location *j* for the flexible activity in the opportunity space, and β_i are the relative weights of the resistance variables. Travel resistance variables limit desired travel and can include, among others, travel time, out-of-pocket costs, exposure during travel to (gendered) harassment and violence, or exposure during travel to air and noise pollution. Determining the nature of those variables and weights involves three consecutive steps. In step 1, experiential, academic and practitioner knowers collectively agree what factors should be included in the model through workshops, surveys, or interviews. These factors can be loosely defined, for example, 'cost of travel'. In step 2, academic knowers define specific travel resistance variables ($v_{i,j}$) that account for the agreed factors and suggest a range for the relative weights (β_i). This is essential to assure that variables and other inputs are defined appropriately and precisely, and that results adhere to rigorous scientific standards and that the sum of weighted variables remains relevant. For example, the loosely defined 'cost of travel' factor from step 1 would now be defined as 'cost of entire trip based on fuel consumption for private travel and ticket price for public transport as a proportion of average monthly individual income' and a specific

range for the corresponding β could be defined as between zero and one [0, 1]. In step 3, academic knowers present a series of scenarios to experiential and practitioner knowers to illustrate how these variables interact, make necessary adjustments, and agree on the final combination of weights and variables to use.
Once the accessibility is calculated for all flexible activities, CoProSTAM ranks the accessibility results and treats the flexible activity with the best accessibility metric as a new fixed activity and repeats the process. If no flexible activities can be performed, the model moves to the next pair of fixed activities.

3.4 Results and final products

It is key that all knowers have an opportunity to scrutinise, interpret, and propose changes to the ways results are being presented and the conclusions that are being drawn from them before results are shared with wider audiences. As in previous sections, the plurality of voice should be followed as guiding principle. If the results are defined by only one category of knowers, there is a risk of epistemic exploitation in which, for example, academic knowers use the input of experiential knowers and the data from practitioner knowers to benefit their own academic endeavour.

4 Application of CoProSTAM

In this section we show how the general methodology for a CoProSTAM described in section 3 can be applied to the specific case of evaluating how different childcare locations in the Corregimiento of Itagüí can access to healthy living for a low-income woman residing in that area.

4.1 Early definitions

CoProSTAM can be illustrated through the following case involving experiential, academic, and practitioner knowers. The group of experiential knowers is entirely comprised of Dimú members and was led by two co-authors of the current manuscript: [omitted for peer review], who is also intern from [idem] and therefore also an academic knower, and [idem]. Other academic knowers are two scholars from the University of [idem], [idem] and [idem], and an MSc researcher from [idem] University, [idem]. [idem] also played a role as part of the cabinet of the Mayor of Itagüí and led the practitioner knowers group which also included representatives of the secretariats of mobility, environment, and health. Collectively these knowers agreed on the following question:

"How can different childcare locations impact the accessibility to a healthy life of a mother living in the Corregimiento of Itagüí with a monthly income equivalent to the minimum national salary?"

The group of knowers and original research question were defined in our first workshop. A flowchart illustrating the different activities carried out, the data collection methods and the corresponding practical stages is shown in Figure 5.

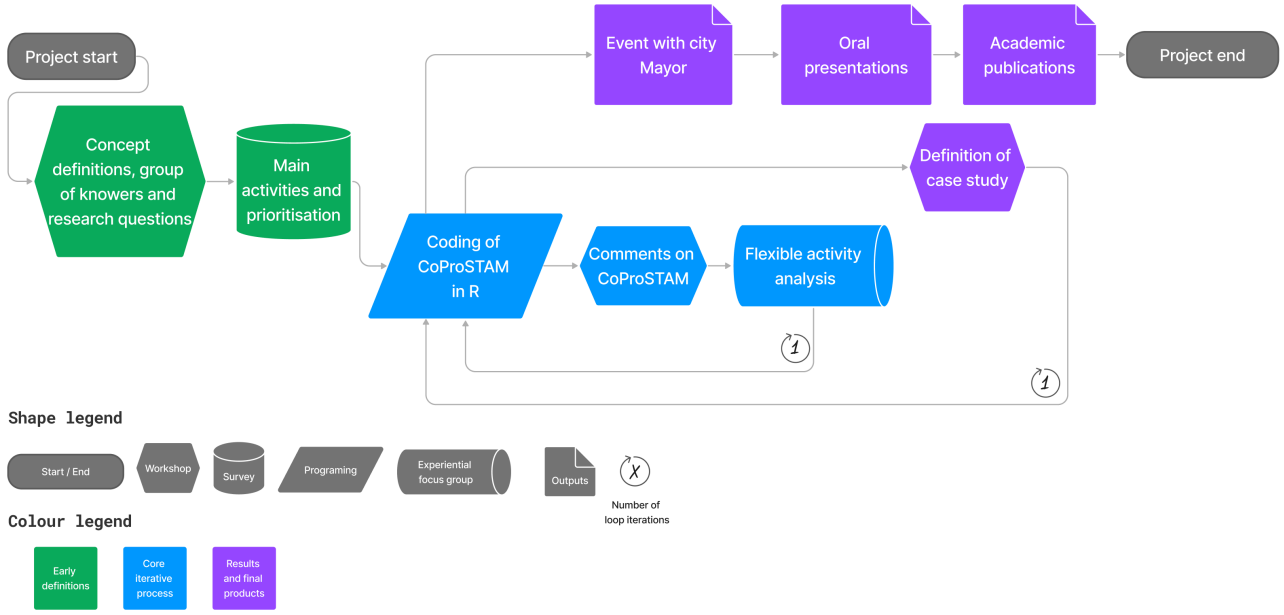


Figure 5. Flowchart of our application of CoProSTAM.

4.2 Core iterative process

The definition of activity diaries began with online surveys distributed to all Dimú members where they were asked about their weekly activities, time required to engage with them, places, and times of the day where and when they would typically undertake those activities, and their preferred mode(s) of travel to these. This was later followed up with a workshop where academic knowers prompted the Dimú group with questions to define an activity programme and described the flexibility levels of each. As explained before, given the low frequency of some activities identified by Dimú as essential for healthy living, activity diaries were defined for one week instead of one day. Members completed up to four diaries each.

Three modes of travel were identified as relevant. First, in the area where the women in Dimú live, public transport services are mainly offered by *chiveros* – a popular transport mode consisting of four-passenger shared rides on a fixed route from the city periphery to the city centre. These services are offered by private providers who are often overseen by violent mafias and operate outside local government regulations. Buses provided by the local government are also available but are not frequently used as they are more expensive and less reliable than the *chiveros*. Taxis and ride hailing apps are available but only used for day-time grocery shopping. Frequent use of this mode is prohibitively expensive for all other trips, but grocery shopping is the exception given the need for carrying multiple bags and other modes not offering a realistic option; turnstiles in buses, for example, prevent women such as those in Dimú from boarding with their shopping

bags. Taxis and ride hailing options are not available after 18:00 because trips to the Corregimiento are not accepted by drivers after dark.[2]

For the accessibility measure calculation, three factors relating to travel resistance variables were initially agreed (step 1) by the experiential, practitioner, and academic knowers: travel time, travel cost, and exposure to air pollution. These were arrived at based on conversations in an early workshop with all knowers, and survey answers from experiential knowers. Besides the intuitive monetary and temporal costs of travel, from our surveys and first two workshops it was clear that environmental variables were of major interest to both experiential and practitioner knowers. In the Medellin metropolitan area poor air quality alerts are announced at least twice a year. Moreover, brick kilns operate in the vicinity of the area where the Dimú women live, making air pollution a palpable threat. Air quality was also frequently referenced as an essential part of the environmental component of healthy living.

Using this information, academic knowers defined the details of the three variables (step 2). Travel time was defined as the estimated time in minutes taken to complete the trip chain from the fixed origin to the fixed destination via an activity opportunity, based on R function *weight_streetnet {dodgr}* (Padgham, 2019). This function was chosen as it uses OpenStreetMap networks which are widely available, allows for variable weights for different travel modes, and checks for transport network discontinuities, all of which are essential features for our purposes. It is also possible to adjust travel times depending on traffic conditions using this package in combination with other data sources, but these were not included in our analysis because traffic conditions vary little for walking and chiveros as the most used transport modes. Travel time was assigned a weight of ß = 0.66 based on data reported by Bocarejo and Oviedo (2012) for Lucero, a low-income, high-density area in Bogota with low access to public transport.

Travel cost was defined as the total cost of going from the fixed origin to the fixed destination via an activity opportunity, as a proportion of average daily income. Defining this cost as a proportion of income allowed concerns over the affordability of trips for the Dimú women, all of whom were on (very) low incomes, to be considered in the analysis. Costs and income were all based on February 2020 surveys and interviews with experiential and practitioner knowers. Costs for public buses and chiveros were based on flat fares for trips to Itagüí's city centre, taxi fares were estimated by experiential knowers based on typical costs and then normalised by distance by academic knowers, and private vehicle costs were estimated using information on fuel costs and consumption provided by practitioner knowers. The weight for travel costs was defined as ß = 11.7 on the basis of information for the Lucero area in Bocarejo and Oviedo (2012).

The third factor, exposure to air pollution, was defined as the time-weighted exposure to particulate matter of aerodynamic radius of 2.5 microns or less ($PM_{2.5}$) resulting from going from the fixed origin to the fixed destination via an activity

[2] Given the proximity to the Equator, sunset in Itagüí remains relatively stable throughout the year, taking place between 17:42 in November and at 18:21 in July.

opportunity. Ambient air pollution exposure levels were extracted from annual raster maps provided by practitioner knowers that were then adjusted for travel mode using the method discussed in de Nazelle et al. (2017). Given seasonal and weekly changes of air pollution, specific dates for analysis can be added and the annual map is adjusted to those dates and times of travel using a ratio based on air quality monitoring stations data. Without specific dates, seasonality effects won't be captured, and annual maps are only corrected using annual average values for weekday/weekend and the time of day (more details on this in a forthcoming paper). Since the travel time variable is defined in minutes, it is important to make it somewhat comparable to air pollution exposure in $\mu g/m^3$. However, the question about how much air pollution is equivalent to a minute of travel remains unresolved in the academic literature (Anand & Hanson, 1997; Solberg & Gamlund, 2016; Tsuchiya, 2000). In this case, we defined the β for air pollution to be 0.006. This corresponds to saying that every minute spent in transport at the annual average concentration of $PM_{2.5}$ in the Medellín metropolitan area is 0.1% more costly than if air pollution is entirely absent. This value was originally suggested by academic knower [family name first author] based on his knowledge of the local context and local epidemiological data of life expectancy reductions due to air pollution.

All definitions proposed by the academic knowers were then validated by experiential and practitioner knowers through consultation in, respectively, a workshop and individual meetings. This resulted in the following accessibility measure:

$$Acc_n = \sum_j Dur_j \cdot e^{-(0.66 \cdot Tt_j + 11.7 \cdot Tc_j + 0.006 \cdot Tpe_j)}$$

[equation 3]

Where j denotes every activity opportunity inside the n-th PPA, Tt_j is travel time to access j in minutes, Tc_j is monetary cost for accessing j as a fraction of monthly income, and Tpe_j is air pollution exposure of accessing j. Note that equation 3 is a simplified version of equation 2. As explained above, accessibility values will be the sum for entire activity diaries for the n PPAs possible either daily (Dacc) or weekly (Wkacc).

4.3 Results and final products

In our third workshop (see **Figure 5**) the group of knowers agreed on the details of the case study to be included in our results. It was collectively agreed to use the example of a 30-year-old woman, mother of two, who lives in the Corregimiento and who's main source of income is the selling of home-made biscuits and cupcakes. The map in **Figure 6** shows the location of her home, and the four nearest publicly funded childcare facilities. It also shows delivery locations of five clients who have contacted her through social media and that she needs to serve first during the week. A target of minimum three clients per day and their general location was collectively set in the same workshop.

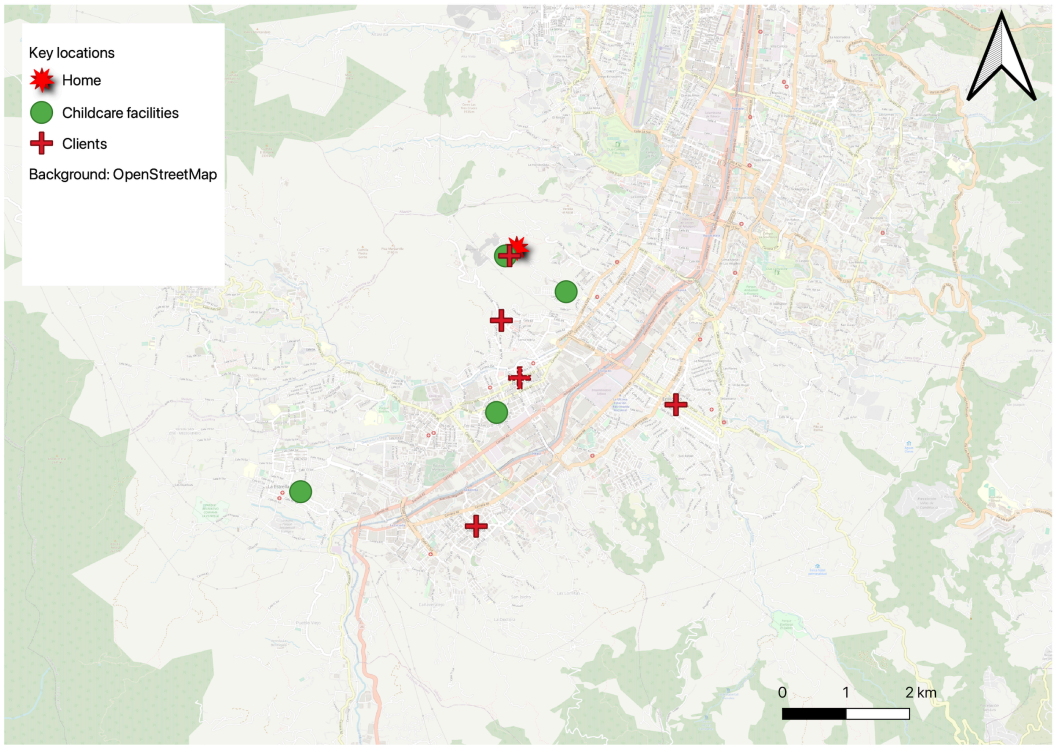


Figure 6. Home, clients, and childcare locations considered for the first day of the week.

Fixed activities in this women's day schedule follow a more or less uniform pattern across weekdays. These start at home where she will make breakfast for her kids before having to drop them off at the childcare at 08:00. She then has some time before she needs to head back home and prepare lunch for her and other family members (those in day-care will receive lunch there), before having to pick up the kids again at 16:00. Weekdays also have a set of flexible activities that include visiting the minimum of three clients per day, grocery shopping once in the week (food component of healthy living), and visiting a pharmacy to collect needed medication (healthcare component of healthy living). This combination of activities is summarized in Table 3. It is important here to highlight the various dimensions of flexibility described before. First, flexible activities are introduced in order of increasing engagement flexibility (less negotiable first) so that CoProS-TAM looks for opportunities for these first. Also, every activity is allocated an 'available hours' range according to their temporal flexibility. For commercial activities this is equivalent to their opening hours, but it can also indicate hours at which family or friends are available for childcare or visits. Finally, the spatial flexibility will be defined by a list of locations where each activity can be undertaken. This list can come from OSM data for various general services and landmarks (e.g. grocery shops or churches), from a predefined list of possible locations offered by experiential knowers (e.g. approximate locations of clients, or friends and family), or a combination of both (when, for example, OSM data on grocery shops do not include locations highlighted by experiential knowers).

Weekends are more flexible, with Sundays having Church as the only fixed activity (essential activity for mental health component of healthy living), and flexible activities including visiting the fitness centre to exercise (physical activity component of healthy living) and having ice cream with the family. Sunday activities are shown in Table 4.

Table 3. Fixed and flexible weekday activities.

Fixed activities

	Arrival time at location	Activity duration	Comments
Home	Start	NA	• Day begins at home
Childcare	08:00	10 min	• Drop-off
Home	10:00	2.5 h	• Prepare lunch for family
Childcare	16:00	10 min	• Pick-up
Home	End	NA	• Home with kids for homework

Flexible activities

	Available hours	Activity duration	Comments
Clients	8:00 - 16:00	15 min	• A minimum goal of 3 visits per day
Grocery shopping	8:00 - 16:00	1 h	• Multiple locations, only once, will need to use a taxi – healthy food component of healthy living
Pharmacy	7:00 – 17:00	15 min	• No specific location and lowest level of priority. Common location for basic healthcare services

Table 4. Fixed and flexible Sunday activities.

Fixed activities

	Arrival time at location	Activity duration	Comments
Home	Start	NA	• Day begins at home
Church	18:00	1 h	• Going to Church is an essential component for mental health
Home	End	NA	• Day ends at home

Flexible activities

	Available hours	Activity duration	Comments
Fitness centre	08:00 – 18:00	1 h	• Physical activity component of healthy living
Ice cream	08:00 – 18:00	1 h	• Leisure time with family

Given budgetary and public transport restrictions, this woman will need to walk to all her destinations except for grocery shopping, for which she will take a taxi.

For weekdays, the option to serve a client, go grocery shopping, or visit the pharmacy, will depend on the opportunity set defined by the time available between two fixed activities and their locations. This is shown in Figure 7. For example, if we are evaluating if she has time to visit a client (and engage for 15 minutes in this activity) between leaving the childcare drop-off at 08:10 and being at home to prepare lunch at 10:00, we can define the areas that can be served from the childcare facilities (shaded red in Figure 7), and from the home location (shaded blue); only clients at the intersection of both areas can actually be served. This intersection is the first PPA (n =1) that in this example has two opportunities for clients (j = 2 for the first pair of fixed activities).

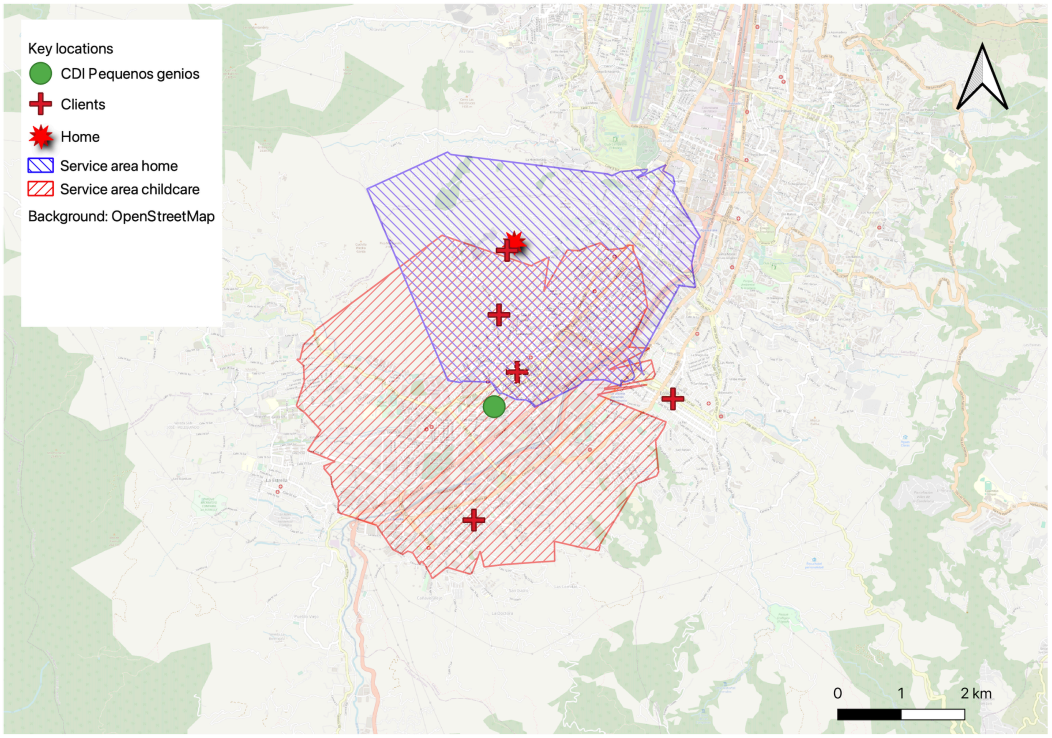


Figure 7. An example of opportunity sets for home and one childcare location. Only the two clients within the intersection of both blue and red areas will be real opportunities for the time available between the two fixed locations.

Using CoProSTAM, we can evaluate how the accessibility measure and the woman's ability to complete her flexible activities change depending on the childcare facility she uses. The results for the first weekday (D_{acc}) are shown in Table 5. Note how the childcare location has an important impact on what the model suggests are viable activity profiles for that day. If the woman in our example uses the Pedregal childcare facility, she will be able to visit three clients (minimum daily target) and dedicate time to grocery shopping, all before 16:00 when she picks her kids up again. On the other hand, she can only visit two clients, if she must use Pequeños genios, or no clients if she must use Huellas creativas.

Table 5. Accessibility and activity diary results (D_{acc}) for the first weekday for different childcare facilities in Itagüí.

Childcare used (from closest to home to furthest)	Pedregal		Cerro luces		Pequeños genios		Huellas creativas	
Accessibility measure result (D_{acc})	2.27		1.61		0.93		0.00	
Clients visited	3		3		2		0	
Grocery shopping	Yes		Yes		No		No	
Activity Diary	Place	Arrival time	Place	Arrival time	Place	Arri-val time	Place	Arrival time
	Home	NA	Home	NA	Home	NA	Home	NA
	CDI 1	08:00	CDI 1	08:00	CDI 1	08:00	CDI 1	08:00
	client 1	08:31	client 1	08:28	client 1	08:28	Home	10:00
	client 2	09:38	Home	10:00	Home	10:00	CDI 1	16:00
	Home	10:00	client 2	12:58	client 2	12:58		
	client 3	13:11	client 3	14:00	CDI 1	16:00		
	Shop	14:10	Shop	14:40				
	CDI 1	16:00	CDI 1	16:00				

Table 5 shows how the daily accessibility (D_{acc}) decreases (from 2.27 to 0.00) as the childcare location is farther away from home. An accessibility of 0.00 means that none of the flexible activities can be undertaken due to the temporal and spatial restrictions set by the fixed activities. As expected, accessibility results are influenced by the number of opportunities available. Given the proximity of Pedregal childcare to the woman's home location, more grocery shop locations are available than when she uses Cerro luces, resulting in higher accessibility values despite a similar activity diary. Note that due to the nature of our accessibility measure, these accessibility values are to be interpreted in comparative terms with a greater number representing greater accessibility. This number is non-dimensional and the value on its own does not have an obvious equivalent in the real world, such as the number of potential destinations that can be accessed, or the amount of time that can be spent there.

The location of the childcare facilities relative to the woman's home creates rippling effects for the rest of the day and beyond. Only with the first two locations can the woman meet the target of serving three clients and complete the grocery shopping. For the other two locations, she will have to postpone grocery shopping to later in the week (i.e., the weekend as she will face similar constraints on every weekday), which will reduce opportunities for the remaining flexible activities. To illustrate the interactions between different days in a week, Table 6 shows the accessibility and activity diary results for two weekdays and a Sunday when using the Pedregal facility.

Table 6. Accessibility and activity diary results for two weekdays and a Sunday when using Pedregal CDI

	Weekday 1	Weekday 2	Sunday

Accessibility measure result D_{acc}	**2.27**		**17.67**		**3.1**	
W_{acc}^{3}					Total for three days = **23.04**	
Total flexible activities (including clients)	4		4		2	
Clients visited	3		3		0	
Activity Diary	Place	Arrival time	Place	Arrival time	Place	Arrival time
	Home	NA	Home	NA	Home	NA
	CDI Pedregal	08:00	CDI Pedregal	08:00	Fitness centre	10:15
	client 1	08:31	client 4	08:28	Ice cream	12:36
	client 2	09:38	Home	10:00	Church	18:00
	Home	10:00	client 5	12:53	Home	19:35
	client 3	13:11	Pharmacy	13:35		
	Grocery shop	14:10	client 6	14:27		
	CDI Pedregal	16:00	CDI Pedregal	16:00		
	Home	17:00	Home	17:00		

Note how the inclusion of the pharmacy makes a big difference to the accessibility level. This is due to several opportunities being available at the time of engagement, and a larger opportunity space than the one for grocery shopping because of shorter activity duration. Note also that because the woman can meet her target of a minimum of three clients per day, she can undertake the remaining flexible activities on Sunday. This would not have been feasible if she had to use other childcare facilities (i.e., Pequeños genios and Huellas creativas) as these would not allow her to complete the minimum number of three clients served on the first weekday and her Sunday would begin by trying to serve previously unserved clients first.

5 Discussion

The co-production elements within CoProSTAM create at least two advantages over traditional approaches to space-time accessibility analysis. They have made possible, firstly, new understandings of the level and nature of accessibility in the context of a very low-income area in Latin America. They have also, and secondly, offered new ways of dealing with some of the epistemic injustices embedded in the way transport models are conceived, developed, and used. In a way, the former results from the latter, given that it was through our attempt to reduce epistemic justices that we found novel opportunities to contribute to the accessibility literature.

The first contribution of our work comes from the understanding of the nature of activities and their interdependence. As mentioned before, academic knowers prompted experiential knowers with questions about their access to healthy living. However, the definition of healthy living came directly from the experiential knowers who emphasized four general topics: mental health, health services,

753 green spaces and leisure, and home and food. This broad, epistemically just defi-
754 nition meant that we considered activity types that are not typically included in
755 accessibility models for health (Cuervo et al., 2024; Hernández & Rossel, 2024)
756 such as grocery shopping, having ice cream with the family and similar leisure ac-
757 tivities, or going to church. It also pushed the conceptualization of our STAM be-
758 yond the timeframe of the day as most of the activities associated to these compo-
759 nents had lower frequencies. Our results emphasize the relational nature of seem-
760 ingly distinct or independent activities that other authors have highlighted (Her-
761 nández & Rossel, 2024; Schwanen & de Jong, 2008), in this case by showing how
762 childcare location affected opportunities for a wide definition of healthy living.
763 Although here we have assumed that childcare centres offer an equivalent quality
764 of service, future work could include discussions on these differences as other au-
765 thors have done (Hernandez & Rossel, 2015).
766 The second contribution, which also results from the co-production elements in
767 our work, relates to the nature and levels of activity flexibility. Early in the core
768 iterative process, it became evident that the key fixed activity for Dimú members
769 was not paid work, but the opening times of childcare centres are. Later it became
770 also clear that a binary division of activities as fixed and flexible was inadequate.
771 One of our workshops and early conceptualizations of the accessibility analysis
772 algorithm by [initials omitted for peer review] still assumed a straightforward dis-
773 tinction of activities into fixed and flexible, but the Dimú members quickly high-
774 lighted that many activities were neither entirely fixed nor entirely flexible. It was
775 tempting to keep simplifying the model by forcing activities into the fixed versus
776 flexible categories, but this would have amounted to wilful hermeneutical igno-
777 rance (Pohlhaus, 2017). We therefore expanded the definition of flexibility in the
778 model by defining three variables of flexibility, namely temporal, spatial, and pri-
779 ority of engagement (**Figure 4**). This meant creating in the model new inputs
780 from Dimú members associated to possible engagement times, bespoke lists of
781 available places, and prioritisation for every flexible activity.
782 Contributions from experiential knowers were also essential in the definition of
783 transport modes and restrictions in time and space. Accessibility measures typi-
784 cally use existing databases for the identification of transport modes (Costa et al.,
785 2021; Xia et al., 2018). Applications such as Google Maps are increasingly used
786 to make modelling tools easy to apply in multiple geographical contexts, but this
787 systematically excludes popular transport alternatives – in our case the *chiveros* –
788 despite their widespread use around the world. Although we have not mapped and
789 fully digitalised these systems as others have done (Klopp & Cavoli, 2019;
790 Williams et al., 2015) we have followed an approach in which experiential
791 knowledge shared verbally is recognised as legitimate and sufficient to be incor-
792 porated into the model. The use of experiential knowledge also allowed additional
793 constraints relating to the inconvenience of public transport buses for certain trips,
794 and the unavailability of ride hailing and taxis due to drivers' reluctance from
795 drivers to take trips to certain areas after sunset. All these restrictions and possi-
796 bilities for travel were constantly mentioned by experiential knowers, and yet are
797 systematically excluded from most accessibility models. These methods can also

be extended to include the use of footpaths as these not necessarily follow the strict hierarchies defined in digital databases (Loor & Evans, 2021).

Importantly, the main objective of CoProSTAM is not to evaluate accessibility levels with greater precision or accuracy, but to offer a transdisciplinary approach to accessibility modelling in which the legitimate concerns of experiential and practitioner knowers are incorporated. If the objective had been to find the 'correct' representation of accessibility, pragmatism would not have been selected as a guiding principle and a more advanced STAM approach than Kim and Kwan's (2003) would have been used as a starting point. CoProSTAM is an effort to combine different knowledges and experiences of mobility in a manner that reduces epistemic injustices. In so doing, it draws attention to daily restrictions that curtail the access of women with very low incomes to the goods and services cities have to offer.

Methodologically, the formulation of, and continuous commitment to, three guiding principles for inclusive participation (plurality, continuity, and legitimacy of voice) helped address some of the ways epistemic injustices play out in traditional research practices. For example, the continuity of voice principle was essential in the recognition of the epistemic labour required from both experiential and practitioner knowers involved in the development process. As a method, participatory accessibility analysis places significant demands on the knowers involved. The experiential and practitioner knowers worked hard during the workshops and other activities, engaging with ideas, concepts and procedures they had not heard of before participating in the research project. In a similar vein, the academics' efforts to facilitate the incorporation of a plurality of voices from low-income women carers, such as financial awards for time spent in our activities and the provision of childcare during the workshops, helped to make the participatory knowledge production more amenable to the inclusion and legitimisation of a wide variety of plural voices.

In future work, CoProSTAM can be expanded and replicated in various ways and contexts, and we hope this paper inspires other researchers to experiment with ways in which epistemic injustices can be reduced in accessibility modelling practices. Section 3 has outlined a general approach to co-produce STAM analysis in an effort to lay the foundations for future work that will likely improve on ours. The code used to model the application in section 4 is available in a GitHub repository [link omitted for peer review] for other researchers and practitioners. Nevertheless, it is important to recognise that the modelling presented here still implies an abstraction and simplification of the realities faced by the women from Dimú. For instance, by focusing on the trips of one individual, CoProSTAM does not consider how people's space-time accessibility is dependent on that of family members and friends (Nansen et al., 2015; Schwanen & de Jong, 2008), or on social attitudes towards specific transport modes, including the social status that is frequently accorded to private vehicles (Ellaway et al., 2003; Li et al., 2018; Lovejoy & Handy, 2011). The importance of these aspects will likely vary between communities and places and will represent important limitations to the applicability of CoProSTAM as introduced in this paper.

Because of its focus on epistemic justice in research with a specific group of people who are affected by intersecting gender, class and locational disadvantages, CoProSTAM demands the use of a greater range and diversity of data and inputs than other forms of (space-time) accessibility analysis. One consequence of this is that CoProSTAM is difficult to scale to larger populations, such as all residents of Itagüí or the Medellin metropolitan area. If scalability is desired, then techniques or algorithms for generalisation will have to be developed. This can be done, for instance, by repeating the current version of CoProSTAM with different groups and/or in different neighbourhoods in the city, and use recurrent findings, insights and procedures across applications to develop a simplified and generalised CoProSTAM. While such generalisation may be desirable from a planning perspective, we also urge caution with this course of action because it reduces the level of epistemic justice that the analysis may be able to offer. In other words, there appears to be trade-off between generalisability and ensuring epistemic justice, and prioritising generalisability is not always desirable. Future research will have to consider how approaches like CoProSTAM can be scaled, and what the implications of scaling are for epistemic justice.

6 Conclusions

In this paper we have shown how CoProSTAM can offer new tools to model accessibility in ways that are epistemically more just and contribute in novel ways to transdisciplinary transport knowledge production. We illustrate how CoProSTAM allows for temporal and spatial restrictions and conceptions that highlight how everyday mobility and access are the result of a complex process of negotiations, variations in the flexibility levels of activities, and the interaction of financial, personal safety, and even environmental concerns.

The well-known modeller mantra that 'everything should be as simple as possible but not any simpler' (attributed to A. Einstein by Sessions, 1950) obtains a new complexion when a transdisciplinary STAM is developed: what 'not any simpler' means, shifts when experiential and practitioner knowers become active partners in the modelling process. Heeding their critically important insights, experiences and perspectives shows that the parameters of simplicity cannot be set by academics alone. Better accessibility measures require attending to epistemic injustices at least as much as improvements in data and geo-computation.

Author contributions

[omitted for peer review]

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