Development and Taxonomization of an Accessibility-First Open Data GIS Standard

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Purpose: Personal mobility in the built environment has been extensively explored by multiple fields of study, but practitioners are still uncertain what information to collect in order to close informational gaps and knowledge barriers to facilitate route-finding and navigation, particularly for people with disabilities. This project aims to provide a framework for accessibility-first map data collection.

Accessibility-first approach: Accessibility is intrinsic to every interface, including 3D spaces where human interactions involve physical and mental engagement with the environment. These interactions utilize various senses, making an object, a path or an area either an enabler or barrier to movement, depending on the combination of the individual, senses used, mobility attributes and the environment. Unfortunately, many surveyors and mapping solutions neglect accessibility altogether, or ignore its multiple dimensions. Embracing an accessibility-first approach prioritizes integrating accessibility seamlessly into interfaces, addressing diverse needs and abilities more effectively and in a personalized (rather than reductionist) manner.

Methods: A framework for an accessible wayfinding application was developed using a literature-based, user-centered, integrative approach. To make the data schema, 549 articles regarding disability and the built environment were screened, resulting in 85 articles representing a diverse population (by disability and country).

Results: Environmental features were identified taking into account the needs of diverse populations and utilizing a relevant subset of over 700 terms identified through the development of human-centered taxonomies from the built environment literature review.

Conclusion: This project represents an extensible, open-data, accessibility-first framework for developing an indoor/outdoor data standard that accounts for diverse and ever-changing factors and preferences, and introduces a variety of approaches to taxonomizing map attributes. This research may be applied in-depth to other locations in the built environment.

1 INTRODUCTION

The construction and usage of the built environment, including buildings, zones, and transportation infrastructure, does not occur in a vacuum, but rather interacts with many systems over the course of the movement of ideas, organisms, goods, and services. Ensuring *mobility equity*, or access of all people in a population to mobility options that meet their needs, regardless of ability, income, race, or location, thus requires a comprehensive examination of factors that affect access to features of the built environment. [1, 2]

The formation of an accessibility-first open data schema is essential to the larger goal of mobility equity because data schemas form the foundation for conceptual models, designs, analyses, and people's views on how the world is constructed. Thus, any biases in such tools and ideas can be perpetuated throughout the data lifecycle and into society and the availability of information and tools. Mobility equity therefore requires *mobility data equity*, or equity in the formation and access of mobility data. Equity can be promoted in the *formation* of mobility data by studying diverse populations, and equity can be promoted in the *access* of mobility data by making the schema freely available to publish, share, and access.

The need for comprehensive accessibility-first GIS data standards is highlighted by the 2016 Accessible Transportation Technologies Research Initiative (ATTRI) User Needs Assessment: Stakeholder Engagement Report. [3] This report involved a literature review, a series of webinars (held in 2015 with close to 600 participants), and an in-person workshop

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focused on determining user needs for equitable transportation. Their target populations were those with disabilities (mobility, vision, hearing, and cognitive), older adults, and veterans.

Collectively, all participants indicated amenity information, real-time transportation, and emergency information to be most important in terms of needs for "reliable, safe, and independent transportation." Among persons with disabilities, the third category of importance was roadway/pathway real-time conditions.

Data on barriers encountered (p. 26-27) and technology availability/issues (p. 29-30) were also collected. Notably, at least 20% of all respondents indicated the following as barriers: [3]

- Lack of signage, maps, landmark identifiers, or announcements (26%)
- Navigation difficulties (unknown arrival time, transfer time distance) (25%)
- Inconsistent accessible pathway infrastructure (23%)
- Lack of (current) accessible service, facility information (20%)
- Lack of available transportation (limited hours, vehicles, service area, etc.) (20%)

Of the five barriers, three pertain directly to the provision of information. These findings emphasize the importance of information to transportation equity and mobility equity as a whole.

Results from the ATTRI workshop held after the webinars further highlight the importance of integrated data standards. The workshop revealed that data integration had the greatest impact on all travel purposes of all technology areas (Wayfinding and Navigation Solutions, ITS and Assistive Technology, Automation and Robotics, Data Integration, Enhanced Human Service Transportation). Furthermore, it emphasized the pressing need for data standards to support data integration by allowing for clear and consistent communication across all entities, including transit systems, consumers, and applications providing transit data, crowdsourcing, route-finding, and multiple modality information. [3]

Despite the need for integrated data standards, current standards represent a patchwork of interests with limited attention to accessibility. Maps overwhelmingly focus on vehicular traffic on roads; and other models like IndoorGML often focus on 3D spatial modeling. Furthermore, mobility equity that accounts for accessibility is rarely examined in conjunction with built environment features; when it is, conclusions are often drawn from a very limited population size and focus on the needs of specific defined sub-populations. Besides problems with variations in definitions, such attempted categorization masks the heterogeneity of said populations and can sometimes hide the plethora of ways in which people of varying mobilities may interact with an object. Lastly, to our knowledge, no current literature taxonomizes features collected from an integrative examination by purposes beyond setting. This paper aims to fill this gap in the literature by answering the research question "What does an integrative, accessibility-first approach to examining the factors affecting transportation equity imply for the structuring and evaluation of an open data schema?" The methods of producing such a schema and various approaches to taxonomizing it are discussed.

2 METHODS

2.1 Literature Review

2.1.1 Query. A keyword/title/abstract search (("mapping standards" OR "pathfinding" OR "navigation" OR "built environment") AND ("impairment" OR "disability" OR "handicap")) was conducted on Scopus on June 20, 2023, with results restricted results to articles from 2021 to 2022 in the subject areas of computer science, engineering, math, psychology, sociology, decision sciences, arts, material science, economics, and multidisciplinary fields. This returned an initial pool of 549 results.

2.1.2 Screening.
Papers were screened by title, abstract, and/or paper content to remove articles without built environment factors (N = 421) and articles for which the full text could not be reached through the authors' institutional libraries (N = 43). This narrowed the pool of eligible papers to 85 results.

2.1.3 Feature identification.
Eligible articles were analyzed manually for built environment terms and context on the study purpose, target population, actual sample population, and sample size. This information was then inputted into a graph database for analysis, with relationships between nodes determined manually based on the literature review.

2.2 Graph database

2.2.1 Schema.
Seven tables were created in the database:

Scopus Info. This table contained all the Scopus metadata on the article, such as title, year, authors, abstract, keywords, publisher, and more.

Raw Features. This table contained raw notes on built environment features identified in an article.

Review Notes. This table contained all other notes taken during review on primary study methodology/focus, target population, details on the population, number of people surveyed (or articles reviewed, etc., depending on the article), target location (ex. indoors, outdoors, public buildings), study country/countries, full-text and/or related links (if different from the DOI link), and other notes.

Nodes. This table stored information on nodes for the main graph structure. Each record represented one built environment feature.

Edges. This table stored information on edges for the main graph structure. Each record represented one (often hierarchical) relationship between built environment features.

Literature Sources - Nodes. This table stored references to the articles that named the corresponding built environment feature for each node. Article references were automatically recorded when features were first identified, and manually added for articles that later referenced the same feature.

Literature Sources - Edges. This table similarly stored references to the articles that provided evidence for relationships between built environment features. Article references were automatically recorded when relationships were first identified, and manually added for articles that explicitly reiterated the relationship.

Completed. This table was used for marking articles as in-progress or completed as nodes/edges were added from the entries in the *Raw Features* table.

2.2.2 Pre-Analysis.
The resulting graph database had 605 nodes and 604 edges.

Fig. 1. Raw Graph Database, Terms Only

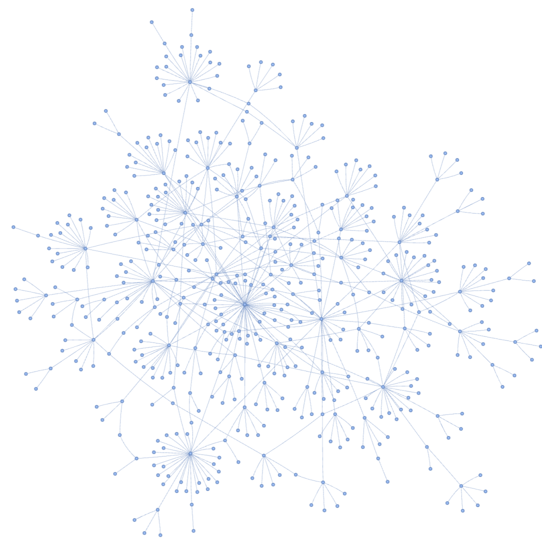


Fig. 2. Raw Graph Database, Terms Only, Hierarchical, showing connections outside of tree structure

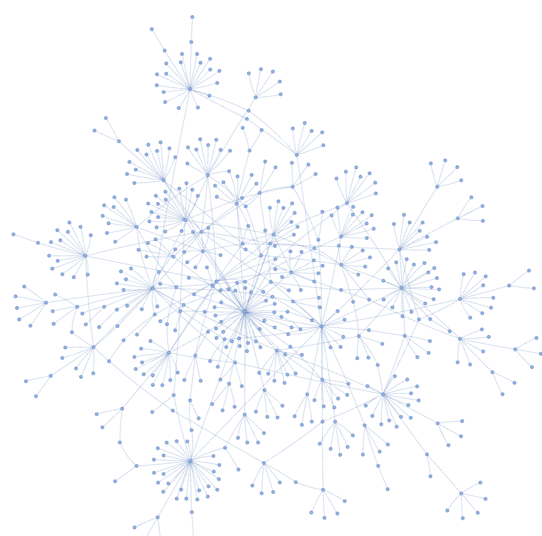
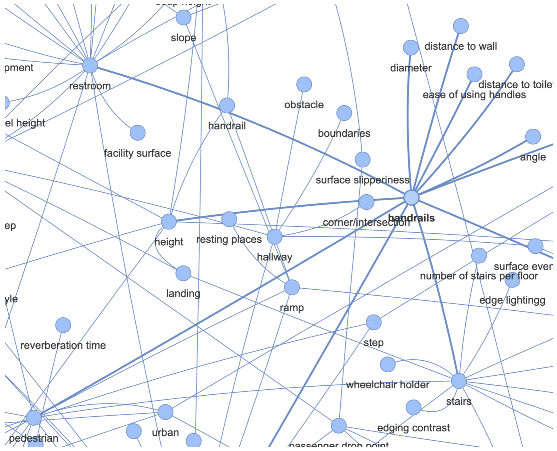


Fig. 3. Raw Graph Database, Zoomed In (Example feature: handrails)



The top fifteen terms (by number of articles referencing them) and corresponding article counts were as follows:

Term	**Article Count**
elevator	19
stairs	19
regularity	15
crossing	14
material	14
width	14
bus station	13
signs/informational aids	13
points of interest	12
slope	12
stairs	12
car	11
curb cut	11
door	11
crowdedness	10

3 INSIGHTS

From initial analysis, the following insights were taken that informed the accessibility-first approach.

Accessibility is everywhere. Accessibility is an attribute of every interface. In 3D space, humans interface with the physical environment with every move, interacting with objects (ex. roads, fields of grass, vehicles, pedestrians, light sources) both physically, to move through the environment, and mentally, for information (especially in relation to creating or connecting the environment with a multisensory mental map of the place). Like impedance or friction, accessibility varies on multiple dimensions. But the total effort required to move through the environment can add up.

Accessibility is multidimensional. Physical/mental interactions may happen through any of the five senses (sight, hearing, touch, smell, taste). Thus an object can be a facilitator in some ways, neutral in other ways, and a barrier in other ways to the same person; similarly, it can take on different roles in being a facilitator/barrier to different people. Depending on the relative importance of an aspect of an object to a person's movement, a person may experience an easier or more difficult time moving through the environment; effort may be reflected physically and/or mentally, and does not necessarily correlate to speed of movement.

For instance, a person with sensory sensitivity may avoid a busy street to avoid sensory overload [4], while a user of a mobility device may avoid it so as not to get hit. A bench may be used as a place for mental rest and for physical rest. Counts of objects may be used for orientation by anyone within a landscape, not just those with visual impairments. And natural lighting influences wellbeing for everyone but may be especially helpful for those with cognitive impairments or difficulties in light adjustment. [4, 5]

Accessibility resides at the nexus of multiple webs of influence. Neither humans nor environments are static; as we move through the environment, we change it and it changes us, both intentionally and/or unintentionally. The information we garner from the environment, who collects such information, and how it is employed is thus important to multiple applications, including wayfinding, audits, and integrative analyses.

4 APPROACHES TO TAXONOMIZATION

After creation of the graph database, links between built environment features and links from articles to features were analyzed in the context of four main approaches to taxonomizing: setting, an integrative social-ecological framework, navigational use, and data collection. By doing so, multiple aspects of the data lifecycle could be addressed, from creation to use.

4.1 Setting

The most widely-used method for taxonomization by articles (and thus the most common relationship depicted in the database) was by setting. Most features could be categorized by transit mode:

- Pedestrian, including movement to/between transit stops
- Public transit (bus, train, subway, air, taxi, streetcar, rickshaw)
- Private transit (including ridesharing)
- Micromobility

Within transit mode, especially the pedestrian mode, features could then be categorized by their location in the built (or natural) environment:

- Indoor
- Outdoor
- Frontages
- Trails

Unsurprisingly, features overlapped between categories. Sometimes this was due to the intersecting nature of the categories, such as the transit type bus involving pedestrian indoor (bus transit hub) and outdoor (bus shelter) features. [6]

Other times, features were simply common to more than one setting, as was the case with *width* as a named attribute (of handrails, elevators, paths, and all manner of features) and with handrails (which appeared in the context of ramps, stairs, and restrooms, with ramps and stairs appearing both in the outdoor pedestrian environment and indoors). [7, 8] While this complicated formation of a tree structure, knowledge gained from this approach to taxonomization was important for understanding the uses of features in multiple settings and situating features within the 3D environment.

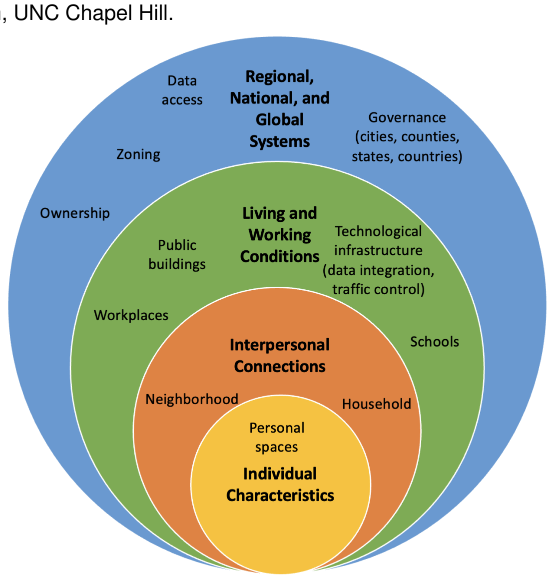
4.2 Social-Ecological Framework

A related approach to taxonomization that subdivides 3D space into layered spheres of influence and connects physical features to relevant factors affecting their creation and usage is the *social-ecological framework* (SEF). This integrative framework, traditionally applied in public health [9], recognizes the effects of multiple systems throughout spheres of influence (individual characteristics, interpersonal connections, living and working conditions, and regional, national, and global systems) on an outcome. Rather than treat such factors as occurring in isolation, each sphere is understood to interact to influence the outcome. Thus, interventions informed by the framework target one or more spheres of influence and generally seek to involve communities affected in relevant research. [9]

In the context of the built environment as examined in the context of transportation equity, such a model can be adapted to understand the factors at each level that influence a person's ability to equitably access transportation (and by extension, built environment features).

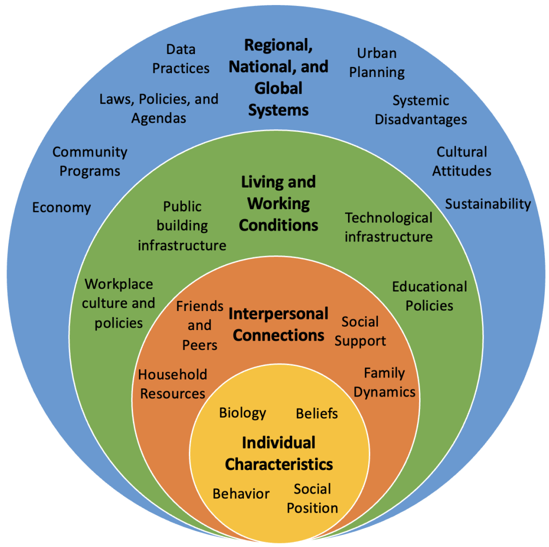
For instance, built environment features could be physically subdivided as follows:

Fig. 4. **The Social-Ecological Framework - Built Environment Features.** Adapted from the MPH Core Team of the Gillings School of Public Health, UNC Chapel Hill.



Meanwhile, the relevant social features that inform and are informed by the tangible features are as follows:

Fig. 5. **The Social-Ecological Framework - Related Features.** Adapted from the MPH Core Team of the Gillings School of Public Health, UNC Chapel Hill.



When analyzing how systems interact to affect an individual's experience through the SEF, it is helpful to step through each level of the framework and elaborate on connections between levels as they surface. This examination used the guiding question, "What influences people's ability to have reliable, safe, and independent transportation in an equitable manner?" This question is adapted from the guiding question of the 2016 webinar held by the Accessible Transportation Technologies Research Initiative of the U.S. Department of Transportation as part of their user needs assessment of individuals with disabilities (mobility, vision, hearing, and cognitive), older adults, and veterans [3].

Note that this paper is only intended to provide an introduction to applying the social-ecological framework to transportation equity. Thus, details on *all* pertinent factors are outside of the scope of this paper.

4.2.1 Individual Characteristics. In the SEF, *individual characteristics* include attributes of a person that affect their experience within the systems they reside in. Such attributes include biology, social position, and beliefs. [9] While attributes vary by individual, this does not mean that attributes can or even should be viewed as personal "problems" for such individuals to solve. They are better objectively viewed neutrally as attributes that may arise from and/or affect *both* personal and environmental factors.

Biology. An individual might be born with or acquire (in the course of aging or in other circumstances) a permanent or temporary condition such as visual, hearing, cognitive, or mobility impairments that influence the way they interact with their environment. Design elements may (often unintentionally) restrict usage of certain transportation technologies to those with certain abilities, thus making such biological conditions relevant to ability to access transportation. [10] For example, while using pedestrian pathways, an individual who is blind may use a cane to detect obstacles [11] and require an audial signal for street crossings, whereas a Deaf individual may require a visual analog for any audial signals. An individual with a cognitive impairment affecting memory and spatial navigation may benefit from way-finding signs placed strategically throughout an area, while an individual with exertion difficulties may benefit from resting areas distributed along a route. An individual with a sensory sensitivity to sound might make use of quiet areas tucked a distance away from a crowded route. Meanwhile, an individual who has limited use of their arms and legs may use a motorized wheelchair and require curb ramps and automatic door openers [3]. Multiple conditions can co-occur; and as detailed earlier, usages can intersect. Note that “biological" does not necessarily imply “genetic".

It should also be noted that while individuals with similar condition(s) are more likely to have similar transportation preferences and/or needs, needs in practice, and the day-to-day impact of one or more conditions in tandem with one another and the environment, can greatly vary. Moreover, certain environmental situations, such as loud noise or pushing a stroller, may simulate the effect of such conditions. Thus, design elements that aid some individuals may be beneficial to many others, regardless of biology.

Socioeconomic Status. *Socioeconomic status*, a measure combining social standing and economic standing and often estimated via income, education level, and/or perceived occupational prestige, is associated with many outcomes, including transportation access. [12, 13]

According to Di Ciommo and Shiftan [13], most papers on transportation equity consider the impact of income and/or car availability on transportation access. In general, low income is correlated with lesser car ownership, a resultant greater dependency on public transport, and less movement over large distances to minimize transportation costs, which have greater significance in context of a smaller budget. [13]

Lower socioeconomic status is also associated with lesser technology ownership [14]. In general, this can impede the ability to retrieve information about transportation and way-finding, use applications for public transit and ride-sharing, and utilize mobile-pay technologies. For the vulnerable populations of veterans with disabilities and older adults, and civilians with disabilities, lack of technology access was identified as a second and fourth greatest barriers to travel that is reliable, independent, and safe [3]. Moreover, lack of access to assistive technology, in particular, restricts the mobility of individuals with disabilities who may rely on technologies like spectacles, wheelchairs, canes, orthoses, or specialized software/hardware to ambulate [15].

Such factors can create a destructive positive feedback loop as lack of transportation and/or technology access restricts an individual’s ability to pursue jobs or related education to increase their socioeconomic status, thus continuing to limit access to associated resources. [15]

Beliefs. Personal values and perceptions about transportation can influence an individual’s mode of transportation and usage in general. Such factors may include perceptions of security, cost, restfulness, comfort, and satisfaction. These perceptions, experiences with transportation, and behavior regarding transportation mode often shape one another and change over time. [16]

An individual may value speed over direct monetary cost and thus use a car instead of walking. They may value environmental sustainability and physical activity and thus use a bike instead of private transportation [17]. Or they may find riding with others as more or less dangerous than other alternatives in certain areas and thus avoid or seek out public transportation methods. An individual may also prefer familiarity over time to destination and thus use modes they are most comfortable with. Lastly, negative experiences (ex. a wheelchair user getting their wheelchair handle broken while on a flight, being subject to a crime on a subway) or positive experiences (ex. being greeted by neighbors) may also negatively or positively influence willingness to use certain transportation modes in the future.

4.2.2 Interpersonal Connections.

People interact with one another both directly and indirectly. Such interactions, especially in the context of households, the local community, and while using transportation, can shape transportation access and usage patterns.

Household Resources and Dynamics. Households may share cars/rides. This can both increase access to transportation for some members or decrease access via unique scheduling constraints and familial obligations.

Households may or may not support an individual's use of certain types of transportation. This can be due to cultural norms, relative status of individuals within the family, and more. [13]

It should be noted that not every 'household' lives in an apartment/house; some live in temporary housing for which transportation access may vary.

Social Support. People who know one another or share some common trait are more likely to carpool or otherwise share rides. People may be influenced by the belief of travel companions. [17]

People may also exchange relevant transportation information via informal exchanges or posting to open data (i.e. crowdsourcing), or come together to build interventions.

Transportation Personnel. Availability and wellbeing of transportation personnel themselves also affects the quality of transportation delivered and community wellbeing.

4.2.3 Living and Working Conditions.

Infrastructure. Availability of different modalities of transportation, neighborhood features, and information availability and technology access are all salient factors of the built environment.

Safety. People tend to avoid places/times where statistically they feel at risk of being victim of a crime. [18]

Workplace Culture and Policies. Return to work may encourage private vehicle ownership or search for a reliable method of transportation to arrive on time; incentives and support for various methods of transportation can also influence transportation use.

Educational Policies. In many states in the US, teens are required to take driver's education to learn how to operate a car. Younger generations are generally also taught how to walk, or use the school bus. These trainings can influence the social acceptability of certain modes of transportation.

4.2.4 Regional, National, and Global Systems.

Data Practices. As data guide policies, correct data and an intentional approach to managing data throughout the lifecycle are necessary. [19] Interfaces and schemas implicitly communicate ideas about accessibility to people and dictate what information is available. Data ownership influences who is represented. And insufficient disaggregation masks inequities.

Land Planning. In the US, many cities are designed for private vehicles. Pedestrian sidewalk connectivity is limited as a result, discouraging walking. [20]

Cost-benefits are often also used for land planning; but such analyses disadvantage those of lower socioeconomic means (because they do not have the means to take significant transportation in the first place) and those with disabilities (who, by virtue of physical limitations and/or lack of accommodations, may be limited in transportation modes). That is, those who are in greatest need for equitable interventions may be most disadvantaged with blind cost-benefit analysis. [13]

Laws, Policies, and Agendas. Policies can dictate standards for the built environment. For instance, an August 2023 ruling was passed on pedestrian right of way, which mandates various inclusive design elements. Formerly, many cited a lack of standards as a reason for not creating ADA transition plans. [21]

Other. Finally, other factors that are equally relevant but will not be addressed here include systemic advantages/disadvantages, community programs, cultural attitudes (especially in relation to thinking of inaccessibility as a problem of an individual rather than a product of the interaction between an individual and their environment), the economy, and sustainability.

Such factors carry great weight in the formation and usage of built environment factors.

4.3 Data Collection

For collection and generation of data, a taxonomy by mode of data collection is important. Specifically, understanding what features/attributes can be collected manually or by certain types of technology can aid preparation for crowdsourcing and other data gathering efforts and provide predictions of data quality.

With this in mind, features can be categorized as follows:

Manually confirmable objects. When there is a clear, agreed upon definition of an object (for example, stairs with multiple steps, doors), confirming the presence of tangible items tends to be doable without special equipment. For instance, items like curb cuts or trash cans may be confirmed via tactile, visual, or (when proficient in echolocation) auditory means. Surface material may also be confirmable via tactile or visual means or by utilizing unique acoustics characteristics to confirm via auditory means. Signals in different modes (visual, auditory, audio-tactile) can be confirmed by their respective mode. Finally, scents and the feeling of air currents may be used to confirm features like bakeries or the use of a path or street for locomotion. It should be noted that objects may be perceivable via multiple senses (auditory, visual, tactile, smell, taste); and signals emitted may overlap and interact. For instance, the sound of feet upon the floor can give information about traffic and acoustics as well as floor material. Relative perceptibility via each sense may influence what equipment/technology and skills are needed for collection of an attribute. [6, 22]

When definitions are not agreed upon, such as for potholes, cracks, or the meaning of tactile signals, items may be harder to confirm; and separate terms may overlap. [23]

Current sensor technology. Mobile phones tend to be the most ubiquitous form of technology, and in present day can measure slope, record noise levels and snippets, and record images. Furthermore, significant processing can take place on-device or elsewhere to identify and categorize objects. However, data collection/transmission is limited by security concerns and people's willingness to record data or be recorded.

Other present-day sensors commonly obtain measurements on light, temperature, humidity, and more.

4.4 Wayfinding

Multiple kinds of navigation exist, for which some features may be more relevant than others than when navigating by a different mode.

4.4.1 Spatial model. Organisms form cognitive maps to aid themselves in navigation. There is ongoing research into how navigational information is encoded in the brain. The two primary proposed frames of reference for navigation are *egocentric* navigation (encoding information relative to one's position in the environment) and *allocentric* navigation (encoding information on other objects in the environment relative to one another). [24]

Per Ladyka-Wojcik and Barense [24], both egocentric and allocentric navigation relies on landmarks, though one can rely on one perspective or the other (or a combination of both) to do actual navigation. For example, for egocentric navigation, one may remember a route as a series of turns, while for allocentric navigation, one may simply track landmarks in relation to one another to determine if one is going in the right direction.

Delving deeper, "Egocentric and Allocentric Spatial Memory in Mild Cognitive Impairment with Real-World and Virtual Navigation Tasks: A Systematic Review" [25] reveals that our medial temporal lobe has various types of cells used in creating a cognitive map, including place, grid, head direction, and boundary cells. This implies that cognitive maps are formed with a combination of landmark knowledge, directional knowledge, and segmentation of paths into reasonable chunks.

Most agree that both models are used in practice by someone navigating, but people disagree on to what extent the information is encoded in one way or another. [24]

4.4.2 Tactical/local navigation. In local navigation, people tend to avoid what they see as barriers. Most potential barriers are physical: cars on sidewalks, stairs, loud noises, crowds. Note that barriers can potentially serve as landmarks as well (and thus be a facilitator).

Conventions may also be seen as barriers/facilitators. For instance, in the built environment, people tend to seek out footpaths to traverse, even during times of heavy pedestrian traffic. In another example, inadequate marked crossing locations led people with visual impairments to cross at speed bump locations. [26]

Boundaries are also important in following along with spatial understanding and determining where one is or where one can go next. Differences in flooring/walls and entrance/exits or stairs/elevators can denote different boundaries. Shorelines, counts of doors, and similar attributes are often used by people with visual impairments to navigate along extended distances, but they may also be used to denote boundaries (in the case of shorelines) and as a marker of progress/location for everyone in general. [26]

4.4.3 Route choices and point-to-point routing. Features that control allowable mode of access (ex. equestrian, bicycle, pedestrian, vehicle; public/private, traffic laws, traffic lights, public conventions, etc) set the framework for route choices.

People tend to consider both points of interest and barriers/facilitators (speed, distance, incline, and other aspects of the built environment, as well as monetary cost, sustainability, safety (ex. crime), weather, and more) in determining a route. An 'optimal' route thus depends on what resources (time, energy) they have to use and what resource usage and points of interest are prioritized. [18]

Barriers may not necessarily be immediately tangible at a given point in time, but people's tolerance for and assessment of risk of certain barriers may influence route choices. [27]

4.5 Other Uses

Numerous other uses exist for mapping data, each with its own focus for features, for instance:

Audits. Audits tend to focus on compliance with laws/regulations that specify a minimal/maximal numerical quantity, such as for bed height. Such laws may work better/worse for specific persons depending on their needs. [28]

Architectural design. Architectural design often requires very detailed specifications where information may be otherwise abstracted. One example is the importance of various types of slopes in a curb cut in building plans instead of the cross slope (main slope), or an analysis of visual contrast of all furniture versus simply noting where information on visual contrast may prevent danger (such as in step edging). [28]

Geospatial analyses. Geospatial analyses of connectivity, food insecurity, etc. usually require sufficiently disaggregated data on the attribute of interest.

5 CONCLUSION

In this paper, we examined various ways of taxonomizing built features identified as most relevant to a diverse population. We saw that accessibility is everywhere, it is multidimensional, and it resides at the nexus of multiple webs of influence.

Further research will analyze the graph relationships more in depth and expand the literature review to include other years. It can also examine the effect of the passage of certain laws on features available in the built environment.

Aside from taxonomizing, various equity-first recommendations for developing GIS standards in general can be identified:

- Hold to universal design principles, and remember that every interface communicates information (whether verbally or not) and that access/accessibility is an inherent part of every interface. What do your designs (ex. schemas, usage of certain icons) communicate?
- Look beyond wheelchair users and those who are blind (two common target populations) when considering factors of the built environment that are especially relevant to accessibility.
- Allow for easy integration with multi-modal transportation.
- Address last-mile (and last 100 feet) accessibility
- Ensure coverage of rural areas as well as urban areas.
- Provide infrastructure for detailed exploration of data (to avoid masking inequities via aggregation).
- Allow for integration with other potentially spatial data sources (environment, demographics).
- Design for interoperability between consumers of information, transit operators, city planners, and application developers.

By keeping the interconnectedness of factors in mind and intentionally being inclusive in everyday actions, one can create a ripple effect of change that aids accessibility in the built environment.

REFERENCES

[1] “Transportation Equity - Transportation Planning Capacity Building Program.” [Online]. Available: https://www.planning.dot.gov/planning/topic_transportationequity.aspx

[2] “Transportation Data Equity Initiative.” [Online]. Available: https://transitequity.cs.washington.edu/

[3] B. Pierce, E. Plapper, and J. Rizek, “Accessible transportation technologies research initiative (ATTRI) : User needs assessment: Stakeholder engagement report.” [Online]. Available: https://rosap.ntl.bts.gov/view/dot/31320

[4] S. Biglieri, “The right to (re)shape the city: Examining the accessibility of a public engagement tool for people living with dementia,” *Journal of the American Planning Association*, vol. 87, no. 3, pp. 311–325, 2021, cited By 7. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85100915173&doi=10.1080%2f01944363.2020.1852100&partnerID=40&md5=f68acad240dd8ba6dee80ef1f4331c2f

[5] O. Narenthiran, J. Torero, and M. Woodrow, “Inclusive design of workspaces: Mixed methods approach to understanding users,” *Sustainability (Switzerland)*, vol. 14, no. 6, 2022, cited By 1. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85126918152&doi=10.3390%2fsu14063337&partnerID=40&md5=07e57b56253a87a5e5c01639696222fb

[6] S. Swaminathan, Y. Yim, and S. Hudson, “From tactile to navtile: Opportunities and challenges with multi-modal feedback for guiding surfaces during non-visual navigation,” 2021, cited By 1. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85106718456&doi=10.1145%2f3411764.3445716&partnerID=40&md5=2722ee365c05e9540cdbe95f1c48645e

[7] T. Baba, “Vidvip: Dataset for object detection during sidewalk travel,” *Journal of Robotics and Mechatronics*, vol. 33, no. 5, pp. 1135–1143, 2021, cited By 1. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85118560297&doi=10.20965%2fjrm.2021.p1135&partnerID=40&md5=227bf489c1a119a877c9e8a3eb145574

[8] S. Arora and A. Deshpande, “Inclusive design—designing barrier-free public spaces,” *Smart Innovation, Systems and Technologies*, vol. 221, pp. 133–146, 2021, cited By 0. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105959696&doi=10.1007%2f978-981-16-0041-8_12&partnerID=40&md5=4c0672b7297cba86a01dbac6f1f2c86e

[9] Chapter 1: Models and frameworks | principles of community engagement | ATSDR. [Online]. Available: https://www.atsdr.cdc.gov/communityengagement/pce_models.html

[10] R. Olkin, “Could you hold the door for me? Including disability in diversity,” *Cultural diversity & ethnic minority psychology*, vol. 8, pp. 130–7, Jun. 2002.

[11] M. A. Williams, A. Hurst, and S. K. Kane, “"pray before you step out": describing personal and situational blind navigation behaviors,” in *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS ’13. Association for Computing Machinery, pp. 1–8, place: Bellevue, Washington. [Online]. Available: https://doi.org/10.1145/2513383.2513449

[12] E. H. Baker, “Socioeconomic Status, Definition,” in *The Wiley Blackwell Encyclopedia of Health, Illness, Behavior, and Society*. John Wiley & Sons, Ltd, 2014, pp. 2210–2214, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118410868.wbehibs395. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118410868.wbehibs395

[13] F. Di Ciommo and Y. Shiftan, “Transport equity analysis,” vol. 37, no. 2, pp. 139–151, publisher: Routledge _eprint: https://doi.org/10.1080/01441647.2017.1278647. [Online]. Available: https://doi.org/10.1080/01441647.2017.1278647

[14] I. Paccoud, M. Baumann, E. Le Bihan, B. Pétré, M. Breinbauer, P. Böhme, L. Chauvel, and A. K. Leist, “Socioeconomic and behavioural factors associated with access to and use of Personal Health Records,” *BMC Medical Informatics and Decision Making*, vol. 21, p. 18, Jan. 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7805047/

[15] “Global Report on Assistive Technology.” [Online]. Available: https://www.who.int/publications-detail-redirect/9789240049451

[16] P. Gerber, M. Thériault, C. Enaux, and S. Carpentier-Postel, “Modelling impacts of beliefs and attitudes on mode choices. Lessons from a survey of Luxembourg cross-border commuters,” *Transportation Research Procedia*, vol. 32, pp. 513–523, Jan. 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352146518301911

[17] R. Arroyo, T. Ruiz, L. Mars, S. Rasouli, and H. Timmermans, “Influence of values, attitudes towards transport modes and companions on travel behavior,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 71, pp. 8–22, May 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1369847819305418

[18] C. Ntakolia and D. Iakovidis, “A route planning framework for smart wearable assistive navigation systems,” *SN Applied Sciences*, vol. 3, no. 1, 2021, cited By 12. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85100708977&doi=10.1007%2fs42452-020-04038-6&partnerID=40&md5=4eb958bd1c8d89104eaa6e59a9734d19

[19] A. Brown, “From aspiration to operation: ensuring equity in transportation,” *Transport Reviews*, vol. 42, no. 4, pp. 409–414, Jul. 2022, publisher: Routledge _eprint: https://doi.org/10.1080/01441647.2022.2064527. [Online]. Available: https://doi.org/10.1080/01441647.2022.2064527

[20] G. Ellis, R. Hunter, M. A. Tully, M. Donnelly, L. Kelleher, and F. Kee, “Connectivity and physical activity: using footpath networks to measure the walkability of built environments,” vol. 43, no. 1, pp. 130–151. [Online]. Available: https://doi.org/10.1177/0265813515610672

[21] U.s. access board - about. [Online]. Available: https://www.access-board.gov/prowag/

[22] H. Palmer Peterson, “Built environment accessibility in the eastern province of the kingdom of saudi arabia as seen by persons with disabilities,” *Journal of Accessibility and Design for All*, vol. 11, no. 1, pp. 115–147, 2021, cited By 2. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85108328449&doi=10.17411%2fjacces.v11i1.294&partnerID=40&md5=1f2de4a1dcd267d673297afb3ec08b28

[23] M. Rosa, G. De Mello, and S. Morato, “Tactile paving surfaces at bus stops. the need of homogeneous technical solutions for accessible tourism,” *Journal of Accessibility and Design for All*, vol. 11, no. 2, pp. 259–294, 2021, cited By 0. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85130516268&doi=10.17411%2fjacces.v11i2.313&partnerID=40&md5=e7d75bea5b7aa280d85efeb268593a93

[24] N. Ladyka-Wojcik and M. D. Barense, “Reframing spatial frames of reference: What can aging tell us about egocentric and allocentric navigation?” vol. 12, no. 3, p. e1549, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wcs.1549. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/wcs.1549

[25] C. Tuena, V. Mancuso, C. Stramba-Badiale, E. Pedroli, M. Stramba-Badiale, G. Riva, and C. Repetto, “Egocentric and allocentric spatial memory in mild cognitive impairment with real-world and virtual navigation tasks: A systematic review,” vol. 79, no. 1, pp. 95–116, publisher: IOS Press. [Online]. Available: https://content.iospress.com/articles/journal-of-alzheimers-disease/jad201017

[26] A. Nagraj, R. Kuber, F. Hamidi, and R. Sg Prasad, “Investigating the navigational habits of people who are blind in india,” 2021, cited By 3. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85119280336&doi=10.1145%2f3441852.3471203&partnerID=40&md5=a05bcd46a0abc57195cfc3c43c300044

[27] S. Anisha and R. Kirkham, “Investigating user risk attitudes in navigation systems to support people with mobility impairments,” 2022, pp. 283–290, cited By 0. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85153387489&doi=10.1145%2f3572921.3572953&partnerID=40&md5=40f7fefc470c8dca3c27a3baa1a8550f

[28] H. Macknight, P. Ohlms, and T. Donna Chen, “Curb ramp and accessibility element upgrade prioritization: A literature review and analysis of multi-state survey data,” *Journal of Accessibility and Design for All*, vol. 12, no. 1, pp. 134–154, 2022, cited By 0.

[Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85131880448&doi=10.17411%2fjacces.v12i1.334&partnerID=40&md5=98355fe0ce66de31b009775c7e7e42e0