International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 3 Issue 6, October 2019 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Are Accessibility Indices, a Smart Decision Support System Tool for Measuring Access of Mobility Impaired in Public Spaces? A Review

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ABSTRACT

Background:
There is a worldwide need for smart decision support system tools to measure, evaluate and improve the physical accessibility for varied mobility disabled users in outdoor and indoor built environment.

Purpose:
1. How the methodology and variables identified in research studies is pertinent for measuring access of mobility impaired in public spaces and development of Accessibility indices?
2. How smart technology is integrated with decision support system tools for measuring the accessibility in public spaces and validated through scientific methods?

Materials and Methods:
The majority of studies published during 2000 to 2017 were included in the review, spread across location, infrastructure and time space based accessibility measures for mobility impaired in public spaces, for all categories of age groups. Comparison of studies at building, campus and city level for analyzing and development of smart decision support system.

Results:
The limitation of decision support system tools integrated with technology considers few variables with one or two types of impairments and fails to demonstrate the conflicting provisions between different disability groups. It supports users and urban planners to map, identify the barriers for intervening in infrastructure improvement and facilitation. The tools brought out social exclusion and disparity in accessing the opportunities of able bodied and disabled persons.

Conclusions:
Research leads to policy interventions, development of smart auditing tools at the planning and design stage for implementing accessibility standards for mobility impaired, elderly and other disability groups. Future studies should focus on real time modeling, utilizing volunteered geographic information for preparation of smart decision support tools.

KEYWORDS: *Disabled, public spaces, decision support system tool, accessibility index, barriers, mobility*

How to cite this paper: Valliappan Alagappan | Saratha Valliappan "Are Accessibility Indices, a Smart Decision Support System Tool for Measuring Access of Mobility Impaired in Public Spaces? A Review" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-6, October 2019, pp.1101-1114, URL: https://www.ijtsrd.com/papers/ijtsrd29338.pdf

IJTSRD29338

INTRODUCTION

One billion people globally experience disability and in that more than 200 million people experience difficulties in functioning. [1] One person out of seven reports a basic activity difficulty in European union like lifting and carrying, walking, bending, sitting or standing. 28%(men 12.9% and women 15.1%) in the European union aged 15-64 reports experience basic activity difficulty. [2] The American community survey estimates the overall disability in the US population as 12.8% and in that over half in the working age of 18-64 and as US population ages, the rate of percentage of disabilities also increased. [3] The Asian pacific countries like Australia, New Zealand disability percentage ranges from 18.5 % to 24 percentages. In Bangladesh 9.1 and 8.7 percentage in Sri Lanka and 2.2 to 2.3 percentage in India and Pakistan and 3% in Singapore. Disability is on the rise due to ageing population and chronic diseases like diabetes, cardio vascular disease, cancers and mental disorders [4].

United Nations convention on disabilities [5] defines "disabilities as those having physical, mental, intellectual sensory impairments, which in interaction with various barriers may hinder full and effective participation in society on equal basis with others." International classification of functioning, disability and health [6] define "disability based on three basic concepts like body function and structure, activity and participation restriction. The definitions stress the environmental and personal factors for inclusive development. Stephen Hawking says, "Governments in the world shall no longer overlook the disabled people who are denied access to health, rehabilitation, support, education and employment." [1]

Public Spaces, Disability and Accessibility

Public spaces include public buildings, outdoor recreational areas like street, lanes, sports complexes, stadiums, parks and playgrounds, open grounds, transportation terminals, retail and wholesale markets, religious and social cultural centers. Public spaces are to be inviting for all categories of persons, age groups and across socio economic groups in the society, removing the divisiveness and making it inclusive for all.

"True public space is recognized as being accessible to all groups, providing freedom of action, temporary claim and ownership" [8-9]. Five spatial rights the Lynch [10] highlights the aspects like "presence, use and action, claim, change and ownership and disposition as degrees of freedom and highlights right of access is fundamental to other rights". Carr et al [9] states that "spatial rights involve freedom of use, most simply the feeling that it is possible to use the space in a way that draws on its resources and satisfies personal needs." The rights to public space are restricted due to temporal and spatial constraints like opening and closing hours, steps, gatekeepers and gates.

Public spaces are the places for social gathering, interaction, meeting point for business, friends, resting places, place for expressing feelings, protest, home for the homeless. The quality of Public space is to remove loneliness and integrates with the various social groups for healthy social life. Whyte [11] demonstrated how public spaces play a critical role in the quality of life in urban areas through street life project in re-designing of Bryant Park. Gehl and Svarre [12] how to study public life, observes the necessary and optional activities related to sitting, standing, walking and used tools to study public life.

The Public sector is slowly retreating from development of public spaces because of private sector involvement and management of spaces and in turn it restricts the user access in terms of intended users, finance and time limitations [14]. Mantey [13] highlighted the importance of quasi-public spaces than fully public spaces in making the social life less exclusive.

Why every human being is not provided physical access to public spaces? Who is not having access? Why? How built environment features and policy legislation was preventing their access? Who is responsible for providing access? How is accessibility defined? Accessibility generally defined as movement from one origin to multiple destinations and from multiple origins to destination/s with ease, comfort and minimal frustration.

Since time immemorial, most of the public spaces in the built environment are planned inaccessible through out the world for the disabled. The spatial planning and design processes since ancient times is only planning for the able bodied and the physical and social spaces is inaccessible for the disabled and this is aptly stressed as "transformed spaces for the disabled" [15]. The disabled people face discrimination of many types such as barriers, insufficient knowledge regarding disability, implementation of policy, legislation and guidelines create exclusion from social life [16-17].

The question of accessibility for disabled in public spaces and buildings gained importance in literature after enactment of American Disability Act Accessibility Guidelines (ADAAG) [18] and subsequently Universal Design in 1997 by Ronald Mace and others. By provision of accessibility in built environment, the professionals are not only assisting the disabled but also contribution to reduction of stigma and prejudice and participating for historic effort of social change and adhering to the principles of constitution like freedom and equality [19]. The reliance of architects on their experience assesses the need of users without obtaining information from other sources or users [20-22].

Accessibility is generally of two types (1) visual accessibility and (ii) physical accessibility and studied in outdoor and indoor built environments. The authors have developed accessibility indices to measure quantitatively, qualitatively and in mixed ways outdoor and indoor environments. An Index (singular) or indices is a sign, indication or measure of something. (Collins dictionary.com).

The index points out where the system needs rectification and appropriate decision will enhance mobility and accessibility levels. The mobility and accessibility is multi-dimensional and the composite index with weighting of individual components indicates the constraints in the existing system. The limitation of composite index is most of the components and its potential relevance will be hidden in the decision-making process [23].

Green [23] developed a "theoretical and methodological framework for universal mobility index to measure multi dimensional nature of mobility by including policy, human rights and built environment measures." Jackson and Green [24] implemented Universal mobility index in a neighborhood activity centre in Kensington, Australia and assessed entire travel chain features like infrastructure, public and commercial buildings, and indicated the will of policy environment component and lack of implementation.

The indices developed in various contexts by author's reveals the performance, compliance; disparity, social exclusion, identifying barriers, user level satisfaction and the organization had utilized the tools for understanding regarding accessibility issues. Choosing the best route based on user abilities and preferences with minimal barriers are integrated with technology for spatial understanding and real time updating data of built environment. Creation of geographic information system database from varying sources will support decision makers in private and public to make decisions that help registered disabled users based on social and economic characteristics [25].

Measurement of Accessibility in different research studies

Accessibility measures in most of the contexts, authors attempts to measure, time, distance, cost factors, which is influenced by physical, social and economic factors. Measuring accessibility measures started with Hansen [26] time space geography by Hagerstrand [27] search for operational form by Ingram [28] Space Syntax measures - social logic of space by Hillier and Hanson [29] The authors researched through out the world in support of infrastructure, location based (cumulative and gravity-based measures), second group focused activity based (time space) and third group as utility-based accessibility measures.

Paez et al [30] categorizes accessibility measures into normative and positive measures. Normative measures study the spatial distribution of number of facilities based on cut off time and distance and positive measures estimates the travel behavior based on actual average travel distance and time, distance decay function, shortest travel time and number of opportunities. Individual or person accessibility measures developed by Lenntrop [31] Kwan [32] and Miller [33] identified the anchors and space-time constraints by studying the behavior of the individuals, time schedules, constraints and potentials in the activity space and develop the accessible locations in space.

The research study attempts the following research questions:

1. Which type of disability and its sub types are studied?
2. How the methodology and variables identified in the research studies is pertinent for measuring access of mobility impaired in public spaces and development of Accessibility indices?
3. How smart technology is integrated with DSS tools in measuring accessibility in public spaces and validated through scientific methods?
4. Any research gaps identified through the literature study?

Materials and Methods

Searches were carried out in Science Direct, Taylor and Francis, Springer, Sage and Wiley-Blackwell online websites, National Centre for Bio technology Information database, California University e-portals, unpublished Doctor of Philosophy thesis, Google scholar using keywords like built environment, mobility, barriers, wheelchairs, disabled, public buildings, public spaces, elderly, accessibility, universal design, barrier free environment, seniors, sidewalks, environment, accessibility index, inclusive planning, design, physical activity, relative accessibility, movement, paths, mobility impaired, smart technology, decision support system, geographic information system etc. through identified articles reference lists and direct contact with the authors and experts.

The inclusion criteria include; (i) Qualitative and quantitative way of assessing the (perceived and measurable) barriers in public spaces (ii) Mobility impaired persons of age above nine years. (iii) Persons using assistive devices like canes, walkers, prosthetics, and wheelchairs. (iv) Control group studies, which includes non-disabled persons (v) Decision support tools to measure accessibility service levels. (vi) Studies conducted in urban areas.

The exclusion criteria include studies like review of accessibility measures, design of assistive devices for mobility impaired, walkability studies, visual, speech and mentally impaired studies. Specific accessibility studies related to parks, playgrounds, gyms, swimming pools etc. The studies identified in the United States of America, European Union, United Kingdom, Middle East and Sub continent. The review of literature included all types of accessibility measures considering all age groups from children above nine years, adults and older people above 60 to 80 years.

The studies were published during 1995 to 2017, with majority of the studies published between 2000 and 2017. The studies, explored the capabilities of decision support tools to understand the access conditions and opportunities available for mobility impaired users at various geographic scales

How mobility disability is defined in different types of Studies?

In ten (N=10) studies the mobility disability is defined as use of prostheses devices like wheelchair users, crutches, Cane and prosthetics. In three (N=3) studies the age, assistive devices and functional limitation (standing and walking) is considered as disabled individuals. In some studies the visual impairment and blind were considered as persons having mobility limitations.

Disability and Smart Decision Support System

The decision support system for measuring, evaluating and decision making for accessibility of abled bodied and disabled were developed at building, neighborhood, institutional campuses and city level. The decision support systems were developed mostly related to pre-trip information and less on real time information modeling. The tools for accessibility had been developed for auditing the facilities and routes while planning and designing of spaces, existing building and spaces adherence to ADAAG guidelines.

Decision Support System at Building Level (2D):

Two studies (N=2) developed accessibility index during normal situations for mobility impaired (particularly wheelchair users) considering aspect of absolute and relative access, location based accessibility measure along with space-time measure framework [34-35]. The studies brought out relative differences in accessibility between disabled and able-bodied individuals in accessing the opportunities in respect to time and distance in university campus and within buildings.

The prescriptive provision of ADAAG guidelines alone will not address the accessibility of a building and how performance based measure supports in enhancing the accessibility for wheelchair users was demonstrated in a toilet layout of a building by using a robot wheelchair user motion planner and how minimal intervention shall make it code compliant and usable [36]. A decision support system developed in the capital city of Jordan to assess safety levels in the buildings for mobility impaired users with range of disability aid combination during fire, the Index equations developed not validated in a case study area [37].

Table 2 shows that Five studies (N=5) stress the relevance for evaluating the building with absolute accessibility measure along with performance based measure and brought out the disparity in number of opportunities available between able bodied and disabled individuals [34-38]. The concepts of weights were introduced into decision support system like weighted grade of overall facilities and frequency in assessing building services [35, 39].

Five studies (N=5) examined the functional access to public buildings, which includes recreational, educational (school), retail and leisure [39, 40, 41, 42, 52]. The studies assessed for identification of barrier through the generic tasks like entering building, circulation elements and facilities and site-specific tasks with regard to its activities. The studies lack discussion regarding how evaluation of each task and scoring methodology had been adopted. The studies brought out exclusionary aspects of able-bodied persons and mobility impaired users [38, 41, 42].

Questionnaire, walk through method, simulation methods were used to identify the barriers and facilitation-required places in the building as described in Table 2. The walk through assessment `was done by audio recording the content and instruments like bicycle odometer for wheelchair users and pedometer for walking members. The students identified more number of barriers with disabilities than able-bodied adults in a school building. Association was not established in any studies between barrier identification and familiarity of the environment. The structural and way finding barriers are related to mobility and visually impaired users respectively. The studies highlight that facilitator is required for wheelchair and visual impairment users in public buildings.

The studies assessed routes from origin to destination, routes and facilities and only facilities based on standard or user inputs. As indicated in Table 1, 70% of variables like access routes, elevators, stairway, entrance (circulation and its elements) and water closet (comfort) included in accessibility indices methodology. The variables (less than 50%) like ramps, water fountains, halls, doors, signage's, lighting, seating, finishes, surface condition, escalators, facilitation elements using human and technology were included in accessibility index development.

Decision Support System (DSS) developed for 3D Built Environment:

Karimi and Ghafourian [43] developed an algorithm in 3D dimensional environment for horizontal and vertical movement for indoor routing for mobility and visually impaired which fulfills ADAAG standards. Kim and Wilson [44] developed indoor and outdoor routing model with the building footprints and generation of three-dimensional building model along with the routing network for able-bodied and wheel chair users compliant with the ADAAG regulations with the support of City Engine. The tool does not address conflicting provisions, user interaction, options and preferences by changing variables of slope, width, surface and curbs for movement between locations.

Dao and Thill [45] developed a 3D Floor plan Accessibility Auditing and visualization tool using GIS for the designers and decision makers for evaluating the floor plans and finding the accessible optimal routes from one origin to one/multiple destination based on impedance computed with Geertman modified potential model and tested in Ellicott complex, campus of State university of New York at Buffalo.

Table no. 2 (Sl.no. 10,11 & 12) shows that the semi ambulatory types like crutches users, prosthetics, and users without aid, elderly and cognitively impaired were not discussed in the research studies. Based on ADAAG standards the feasible routes were developed, but access standards like access routes, turning radius of wheelchair users are debated and proved them insufficient for their movement and difficult for users in various studies.

Decision Support System at Institutional Campuses and Neighborhood level:

The decision support system developed in the campus environment demonstrates manually the amount of barriers, relative differences between able bodied and disabled individuals [34,46]. Mathews and Vujakovic [46] demonstrated the relative access concept in Coventry University campus before Church and others [34] as indicated in Table 4. The authors demonstrated the wheelchair users travel at least 300m further than the able-bodied users and stresses that it leads to increased time and effort [34,47,48]. Church [34] demonstrates concept through route penalty for the wheelchair users in comparison to able bodied. Few changes in the built environment barriers will reduce route length significantly in comparison to able bodied.

The safety aspects are more considered in route choice than the distance and time to reach an opportunity or set of activities and at the same time the studies suggest a maximum detour distance [48]. The smart tools facilitates the disabled to make pre-trip planning from origin to destination based on the information available through maps or online apps developed for particular user group [49-50].

These tools create autonomy for users in built environment without much dependence on others for day-to-day activities. The tools are very useful to the users and urban planners to map, identify barriers and intervene where required facilitation is necessary. As discussed in Table 4 regarding the validation through the simulations, web enabled software's give scope for the users and planners to alter the requirement based on user preferences criteria and utilizes permutation and combination aspects of the tools to understand barriers in urban landscape [48,49,50,51]. The limitation of the tools it considers very few criteria and one or two types of impairments and fails to demonstrate between conflicting provisions of different disability group users.

Table 3 describes that 80% variables related to sidewalk like surface type, condition, slope, availability of dropped curbs and its slope and less than 40% variables like sidewalk width, length, material, steps, furniture, traffic, on street parking discussed in index development studies. The variables like distance-decay, curb orientation, lighting, signage's and sub variables were not addressed in research studies for accessibility index development.

Decision support system at City Level:

At City level out of ten studies, seven studies (N=7) purely of quantitative (objective based) and two studies (N=2) are objective and perception based and one studies (N=1) purely perception based. As discussed in Table 6, five studies (N=5) used computer-aided tools like simulation, GIS and client server architecture for assessment of routes for wheelchair users [53,54,55,56,58]. A decision support system developed for identifying an optimal sidewalk route in Northampton, United Kingdom through GIS and web enabled for different types of wheelchair users for six routes based on the age, sex and fitness of the users by considering slope, surface types and dropped kerbs variables [56].

An index developed to assess the performance of sidewalk for wheelchair users in the city of Sao Carlos, Brazil [57] the decision support system was prepared with weighting of variables (longitudinal profile, surface, material) and validation by the wheelchair users and technical assessment of the routes by the experts. The tools developed in both the contexts help planners and users in identifying the barriers in urban areas. The limitation of the studies is only few variables related to sidewalk are considered for index development and not integrated with technology.

Table 6 shows that nine studies (N=9) assessed entire existing routes of the city for accessibility of wheelchair users. Vale et al [55] differentiates between ratio and gap method for identifying the accessibility disparity between abled and disabled users using GIS spatial network analyst for identifying the number of opportunities available for disabled and abled bodied using the sidewalk information in the city of Lisbon.

Casas [58] assessed the number of opportunities at Greater Buffalo, Niagara Region, Western New York in an individual activity space and compared level of access between disabled and non-disabled groups. Two studies (N=2) highlight the social exclusion and disparity in accessing number of opportunities in urban landscape [55,58].

Pascal and Zielstra [53] developed algorithm for assessment of footway information of cities collected through Open Street Mapping (OSM) project and further used for routes computation based on percentage of information. A decision support system was developed at two contexts based on OSM and in-house algorithm development for route calculation for wheelchair users at Halden, Norway and Bonn, Germany. [51,53,54]

Holone et al [51] developed routes with help of user feedback using four tasks through iteration between two-way points of ten to thirty minutes using "our way algorithm". The question is "Who is giving feedback? Whether the person is abled bodied or disabled person? What category of disability? Whether using mobility aids or not? What is the age and weight of the person?" Based on last ten-user feedback and their profile, date and time helps users in making decision to choose the optimal routes.

Wennberg [59] and Rosenberg [60] identified through perception study the barriers and facilitator in outdoor environment for aged and mid life aged sample population. Both studies assessed variables like curb ramps, lighting, street crossings, surface conditions and facilitators like benches and stairs using participant observation and content analysis. The studies identified barriers like absence of lighting, benches, lack of kerbs at zebra crossings, no communication signs and baskets.

Table 5 shows that 86% variables like presence of sidewalk, width, material, smoothness, slope, dropped curbs availability and slope, street crossing discussed in accessibility index development studies. Less than 50% of variables like orientation, orderliness, and weather and traffic conditions discussed in the studies. Only 15% technical variables like camber, curvature used in sidewalk accessibility studies.

The studies discussed above not assessed barriers like sign boards, orientation, heavy crowd movement, types of curb cuts, trees, lamp post, display boards, hanging wires, parking of vehicles, cycle parking, placement of utilities like transformers, signage's regarding change of levels not discussed in index development. The facilitation aspects like real time assistance, emergency provisions, and assistance by the roadside persons not addressed in none of the studies. The only limitation of these tools, it shall not be used by people of severe limitations and person who lack computer, smart apps and, mobile knowledge.

Results

There were 29 studies, which are directly, or indirectly measuring accessibility in public spaces for mobility impaired. The Decision Support Tool (DST) was of two types: (i) absolute measures and (ii) relative based accessibility measures. Few DST were developed with quantitative (experts auditing it technically) and qualitative (perceptions of disabled users). Out of 29 studies only five studies (N=5) address quantitative and qualitative aspects, three studies (N=3) of qualitative aspects and rest of the studies of purely quantitative in nature. The studies utilize the perception of users for identification, understanding and ranking/scoring of barriers.

At the outset the studies discussed the majority of variables under various aspects as showed in Table 7 and minimally discussed variables like orderliness (graffiti, litter), Orientation (signage's on horizontal and vertical levels, curbs), weather conditions, technical aspects like camber, curvature, bullnose, finishes, materials, facilitation aspects. The DSS tools mostly developed to assess the present conditions of the built environment with help of experts/decision makers, but some DST are developed for users to assess existing conditions of the routes before traversing the pedestrian networks. These tools provide information to the users to take decisions for reaching desired opportunities.

SDST tools are developed for the designers, planners to assess the accessibility in the design stage and rectify the constraints to make it inclusive [45] Most of the papers discuss the concept of absolute access based on standards and guidelines. ((ADAAG-1990) [27], Equality Act, 2010 [7], Accessibility and Barrier Free Guidelines, India (CPWD-2014) [61], Canadian, Australian and European Guidelines)).

Seven Studies (N=7) discusses the relative accessibility, accessibility disparity and gap [34-38,46] and brought out the social exclusion aspects of the disabled [56]. The decision support tools brought out social and physical exclusion in spaces between disabled and non-disabled users and highlight exclusion in the public spaces for decision makers.

One Longitudinal study (N=1) assessed the user feedback on pre and post implementation accessibility measures and satisfaction levels [59]. The DST developed in outdoor environment highlights the barriers in the urban landscape with the help of Geographic information System, Simulation and Web based tools and some tools generate only reports indicating the priority of implementation [47-56,58]. One study (N=1) developed at building level using simulation tools for representing spatially the barriers for mobility impaired in reaching the opportunities [19]

The research studies have not addressed, (i) How each age groups, gender, fitness level and type of assistive device users view different types of barriers? (ii) Which barrier is considered difficult by age groups and gender (iii) which barrier shall be negotiated? (iv) What type of facilitation is required for which type of barrier? Are to be addressed in further research studies.

Many research studies have to be conducted in varied contexts for incorporation of accessibility provisions for disabled in the existing buildings (retrofitting measures) for various built forms, sizes and area of building. Decision support systems are to be developed: (i) Which built feature need attention of authorities? (ii) Which feature under implementation? (iii) Which feature requires finance for implementation? Which built environment feature needs emergent directions?

Different types of weightage method like Delphi method, successive interval method, analytical hierarchy process, absolute restriction and relative method, relative reduction method, user feedback and simple weighting method, based on frequency of answers for the barriers [43,46]. The impedance value for each segment based on user preference has been computed based on weightage derived from user perspective. In some studies, impedance level has been computed based on weightage by the user and assessment of a built feature by accessibility standard and normalized by the maximum value of that standard [50,54]. Volkel and Weber [48] evaluated using simulation, the routes by user feedback and suggested for their improvement.

Most of the studies undertaken in accessibility are the methodologies, which indirectly helps the decision makers in understanding the barriers in the public spaces. Functional access had been evaluated for disabled users based on generic and site specific tasks, in assessing barriers and required facilitation. Most of the decision support tools are developed based on expert's opinion, suggestions and users perspective and developed equations for applying in real world. There are inherent limitations regarding the scientific validity and reliability of the tools developed at various contexts.

Table 4 (Serial no. 4 & 5) indicates that two studies validated the unique identified routes based on altering the weights of parameters and user preferences through simulation and visualization. The user specific variables are altered using simulation software for understanding system effectiveness in identification of routes that are feasible for varied mobility impaired users [53,54]. The simulation and web based tools that allows for more customization of parameters will identify preferences and options based on user needs. The tools lack user specific preferences like age, type of mobility devices, men, women, fitness level and severity or intensity of impairedness.

As described in table 2 (Sl. No. 10,11 & 12) the validation had been carried out for the indoor routing network based on set of origin and destination pairs, connected and disconnected networks between two buildings with non symmetrical distribution of points of interest. The validations of routes were generally digitally tested in the lab trails through simulation and visualization, fellow professional experts, tested with users and through social observation. The web access tool[47] evaluated by experts regarding page layout, route utility, page loading and interaction with the website.

Discussion

There are some studies indirectly assesses the knowledge of accessibility measures like existing decision support tools pro and cons, legislative measures in the perspective of municipal planners and accessibility specialist [63]. Agent based model are used in studies to assess behavior of pedestrian in space [64]. There were studies, which discusses about space syntax (visual accessibility) in public spaces, which addresses the configuration of geometric spaces, in terms of depth perception, impedances from origin to destination and connectivity [29]. The various methods like walk through and perception method, standards/guidelines and virtual reality based assessments used for evaluation of built environment [65-66].

The words like index, indicator are used in studies to understand amount of opportunities available in barrier or obstacle ridden public spaces. Before development of any indexes two aspects to be studied: (1) attributes discussed are reliable and valid were to be tested and (2) how the attributes are perceived by persons of different groups of income, gender, educational backgrounds and health conditions? [62].

The American disability accessibility guidelines amended in 2010 discusses only the standards for manual wheelchairs and classified their standards based on age above 12 years considered as adult and below twelve years as children. The standards like forward and side reaches of objects, facilities, ramps and circulation elements related to children in manual wheelchairs are in development stage. The standard, which are developed in western and eastern countries, is based on the ergonomics of wheel chair and not based on sub classification of mobility impaired persons assistive devices like crutches, prosthetics, walkers and without mobility aid. The research studies have to be undertaken regarding the conflicting provisions between the disabled groups.

Conclusion

Accessibility studies focuses on design level (buildings), side walk conditions and few studies focuses on wheel chair ergonomics, measuring technically the surface conditions, types, when travelling on slope surfaces, hand rim loading, the amount of force required by the facilitator while pushing wheelchairs using front, back wheels and impedances had been studied.

The decision support tool to measure accessibility had been developed using quantitative and qualitative approach, but in some cases mixed methods is adopted. The former studies evaluated the buildings based on accessibility guidelines and some studies focused purely on perception based and after enactment of United Nations legislation in 2002, authors had started focusing on person and built environment interaction studies.

The DST developed at many contexts does not take the temporal aspects, barriers, facilitators associated with accessibility measures. The Access level varies during day and night time in urban landscape and buildings because the facilities and services are required for 24hrs period. The decision support tools developed at public spaces and buildings in reaching opportunities do not distinguish based on age groups; intensity of disability and it is not comprehensive in nature.

The barriers and facilitators as discussed in figure 1 experienced by different disabled age groups vary across urban areas. DST shall utilize the volunteered geographic information and user feedback for identifying barriers and facilitators. The users giving information have to be trained for inputting the information in standardized format.

Few of the variables are taken for DST and it is difficult for these tools to perform in an inclusive way to include all categories of disabled people. Both objective and subjective based measures are essential to understand the issues of accessibility in an area and targeted interventions to achieve desired outcomes [67].

The studies suggest that decision support tools are not complete without focusing on three aspects like positioning, routing and guidance. For Indoor guidance, the landmarks play a vital role in route communication to the varied user age groups by maps, voice based and augmented reality [68]. Future research studies have to focus in identification of landmarks based on disabled groups preferences and three dimensional smart tools, which integrate indoor and outdoor routing together considering the factors and technologies varying between built environment contexts.

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Table: 1 Percentage of Variables utilized at Building Level for Index Development (Out of 10 studies)

Variables	Percentage
Entrance, Stairway, Elevators	70
Corridors/Circulation and Water closet	60
Urinals, Washroom, Water fountains, Doors, Room/Hall	50
Ramps, Escalators, Turning Radius	40
Pavements, Signage's, Finishes, Materials, Parking	20
Lighting, Seating	10

Table 2 Summaries of Article Elements At Building Level

SI. No.	Authors and Refereed/ Not Refereed	Case Study Area and Country	Samples (n)	Parameters and Variables	Method of Assessment	Assessment of a route/facility/ route and facility	Smart System Enabled	Main Focus	Validation	Study Type	Accessibility measure
1.	Al Zoabi [37] (Refereed)	Jordan	Mobility impaired with range of mobility aid combination and abled bodied individuals	Time, Safety Criterion, loading strength, touch, smell, sight, ambient temperature, strobe light, smoke.	Quantitative	Access and Egress routes during emergency	Not enabled	To assess safety levels in a building for mobility impaired individuals with a range of disability aid combination during the fire emergency. (Social Exclusion studies)	Practicing architects in the Jordan.	Cross Sectional	Time Space Measure
2.	Han et al [36] (Refereed)	Standford, USA	Wheelchair users	Doors (pull and push side), toilets, urinals, turning radius, stairs.	Quantitative	Route and Facility	Enabled - Through Simulation (Robot wheelchair user motion planner)	Performance Analysis of a building for access route standards (ADAAG guidelines, 1990) prescribed for wheelchair access.	Making changes in the layout, the validation is carried out for better access	Cross Sectional	Location and Infrastructure
3.	Church and Marston [34] (Refereed)	University of California, Santa Barabara	Wheel chair users and ambulatory persons	Corridors, Stairways, Elevators and Pavements.	Quantitative	Routes to access a facility or set of facilities	Not Enabled	Decision support system using location based methodology to assess the accessibility barriers in an institutional building. (Social Exclusion Studies)	Real time validation with the users by walk through assessment	Cross Sectional	Location, Time space measure and Infrastructure

4.	Neela Thapar [38] **(**Refereed)	30 Public buildings at Greater Boston	Mobility impaired not using wheelchairs, wheelchair users, visually impaired and a Control	Percentage of tasks performed, Time, distance, Barriers and facilitators.	Quantitative	Routes and facilities	Not Enabled	Functional Access to facilities assessed along with barrier and facilitator identification. (Social Exclusion Studies)	Real time validation with the users by walk through assessment	Cross Sectional	Location and Infrastructure
5.	Sakkas [35] **(**Refereed)	University Building, School of applied Technology, Institution of Crete, Greece	Wheelchair users and able bodied persons	Building services, frequency, quality, distance decay.	Quantitative	Route to access a particular service	Not Enabled	Decision support system using location based methodology to assess the accessibility barriers in an institutional building. (Social Exclusion Studies)	Developed the framework but not validated by the wheelchair users.	Cross Sectional	Location and Infrastructure
6.	Bendel Judith [39] (Not Refereed)	Eight Major Categories of Building, Israel	Mobility impaired and its types, Visual and auditory impairments	Specific elements and facility	Quantitative	Specific elements and facility	Enabled	An Audit and decision support system for evaluating the accessibility of public facilities for different types of impairments	User Satisfaction	Cross Sectional	Infrastructure
7.	Pivik [40] **(Refereed)**	29 Schools (Student with disabilities) and 22 schools (Students without disabilities) in School board in Ontario, Canada	Mobility impairment (electric, manual wheelchair users, crutches and walkers), vision and hearing impairment. Students nine years and above	Entrance way, doors, passageway, washroom, signages and safety, water fountains, elevators, classroom, stairs, library and recreational facilities.	Quantitative (Walk through method)	Routes and all facilities	Not Enabled	To identify which group of people is identifying more number of barriers in the School building. Principal, students and special education resource teacher.	Different impaired users	Cross Sectional	Location and Infrastructure
8.	Poldma [41] (Refereed)	Alexis Nihon Mall, Canada	Visual impairment (dog) Visual impairment (Independent movements) and Wheelchair users and researcher with disability	Major Design elements, circulation areas, finishes, materials, lighting and signage's.	Qualitative	Routes and Facilities	Not Enabled	A Qualitative methodological approach to understand the time space barriers in the commercial Alexis Nihon mall in Canada. (Social Exclusion Studies)	Different impaired users	Cross Sectional	Infrastructure and Time space measure
9.	Pereira [42] (Refereed)	Marcana Stadium, Rio de Jeneiro, Brazil	Wheelchair users	Accessibility, attractiveness, conveyance, urban security and Traffic security	Quantitative	Facilities	Not Enabled	Evaluation of the access condition of wheelchair users in sporting mega events	Wheelchair users	Cross Sectional	Infrastructure
10.	Karimi and Ghaforian [43] **(**Refereed)	Mocked up five storey building and for validation of the algorithm	Mobility and Visual Impairment	Hallway Network, Entrance /Exit Door, Room/Hall, Drinking Fountain, Water Closet, Elevators, Escalators, Stairways.	Quantitative	Routes and Facilities	Enabled	Developed an algorithm for 3D indoor routing for mobility and visually impaired based on ADA standards	Validation is done with origin and destination pairs, altering the nodes and facilities.	Cross Sectional	Infrastructure

11.	Kim and Wilson [44] (Refereed)	Spatial Sciences Institute Building in the basement of Allan Hancock foundation building	Wheelchair users and able bodied	Staircase, Ramp, Elevators, corridor network.	Quantitative	Routes	Enabled	Developed indoor and outdoor routing model with the building footprints and generation of three-dimensional building model along with the routing network with the support of City Engine for wheelchair users based on ADA standards	Validation is done in virtual reality by altering the built features for wheel chair users and able-bodied individuals.	Cross Sectional	Infrastructure
12.	Dao and Thill [45] (Refereed)	Ellicott complex, Campus of State University of New York at Buffalo	Wheelchair and able bodied users	Elevators, Stairs, Rooms and Corridor Network, Main Entrances, Exit Doors, Food court, meeting room, Travel Time	Quantitative	Routes	Enabled	Developed a 3D Floor plan accessibility auditing and visualization tool for the designers and decision makers for evaluating the multi story building floor plans	Validation done in virtual reality creating alternate scenarios by adding links, exits during emergency and non-emergency situations for wheelchair and abled bodied users.	Longitudinal	Infrastructure

Table: 3 Percentage of Variables utilized at Campus level for Index Development (Out of 05 studies)

Variables	Percentage (%)
Surface type and condition, Slope on the way, Dropped curbs Slope of the curbs	80
Sidewalk length, Street crossings	40
Sidewalk width, sidewalk material, steps, furniture, sidewalk traffic, on street parking	20

Table 4: Summaries of Article Elements At Campus Level

Sl. No.	Authors and Refereed/ Not Refereed	Case Study Area and Country	Samples (n)	Parameters/ Variables	Method of Assessment	Assessment of a route/facility/ route and facility	Smart System Enabled	Main Focus	Validation	Study Type	Accessibility measure
1.	Mathews and Vujakovic [46] (Refereed)	Coventry University Campus, UK	28 wheelchair users for identification of barriers 10 wheelchair users for weighting the barriers (motorized and self propelled) Age groups: 18-58 Team of local geographers	High Kerbs / Lack of dropped kerbs, steep gradient on ramps, uneven paving slab, rough or cobbled surfaces, slippery surfaces, narrow pavements, street furniture, congested pavements.	Quantitative and Qualitative	Route (Sidewalks)	Not Enabled	A series of route maps was prepared with the computation of mobility index values based on identification and weighting of the barriers by the wheelchair users for identifying the categories of accessible areas in the campus.	The wheelchair users not validated the identified routes based on weighted mobility scores.	Cross Sectional	Infrastructure
2.	Church and Marston [34] (Refereed)	University of California, Buffalo Campus . USA	Wheelchair and Ambulant User	Slope too steep, Broken and cracked asphalt, cross bikeway.	Quantitative	Route (Sidewalk)	Not Enabled	The importance of relative access along with absolute access for wheelchair users is demonstrated in University of California, Santa Barbara Campus for barrier removal at building and campus level.	Validated by the wheelchair users.	Cross Sectional	Location, Infrastructure and Time space measure

3.	Sobek and Miller [47] **(**Refereed)	Utah University Campus, USA	Peripatetic and aided wheelchair users.	Curb cuts, Sidewalk ramp, Handicap entrance, Parking.	Quantitative	Routes (Sidewalk)	Enabled-Web based interface	A U-Access tool developed through world wide web for identifying the obstacles and constraints in the built environment and finding the shortest and most feasible route for three categories of mobility impaired users like peripatetic, aided and wheelchair users based on the differing physical ability levels of the users.	Route Experts and wheelchair users.	Cross Sectional	Infrastructure and Time space measure
4.	Thorsten Volkel and Gerhard Weber [48]	University of Dresden, Germany	38 Visually impaired, and Blind, Wheelchair users and elderly at the simulation stage	Safety and Length	Quantitative	Routes (Sidewalk)	Enabled (Simulation) J2EE server for simulating the real world.	Developed an algorithm called "**Route Checker**" based on users profile, rating and annotated data for personalized multi criteria routing for mobility-impaired pedestrians (visually impaired, blind and wheelchair users)	Not validated by the users	Cross Sectional	Infrastructure
5.	Karimi Ha and Kasemsuppakorn [49] **(**Refereed)	University of Pittsburgh Campus, USA	Wheelchair users	Width, Length, Slope, Sidewalk Conditions (cracks, uneven surfaces and manhole covers), Sidewalk traffic.	Quantitative	Routes (Sidewalk)	Enabled (Simulation) Microsoft Visual studio/Net and Mat lab	Personalized routing for wheelchair was developed based on pre trip planning mode based on user preferences and environmental factors.	Altering the variables and finding the routes based on origin destination pairs on simulation.	Cross Sectional	Infrastructure
6.	Tajgardoon M and Karimi HA [50] **(**Refereed)	University of Pittsburgh Campus, USA	Wheelchair users, Blind and Vision impairment	Sidewalk surface type, Surface conditions, Cross walk, Number of steps.	Quantitative	Routes (Sidewalks)	Enabled (Simulation) Mat lab	Evaluated the sidewalk accessibility for Wheelchair Blind and Vision impaired users with the support of simulation and visualization software at Pittsburg university main campus	Altering the variables and finding the routes based on origin destination pairs on simulation.	Cross Sectional	Infrastructure

Table 5 Percentage of Variables utilized at City level for Accessibility Index Development (out of Seven Studies)

Variables	Percentage (%)
Presence of Sidewalk, Sidewalk width, Sidewalk material, Smoothness of surface, Slope on the way, Dropped curbs, Slope of the curbs, Street crossing	86
Surface Type, Steps, Lighting, Furniture	72
Step Height, Orderliness (Graffiti, Litter), Grooves on the drainage, Stairs	43
Absence of sidewalk, Landing, Orientation (Signage's), Sidewalk traffic, Weather Conditions	29
Camber, Curvature, Shops, Postboxes, Handrail on Stairs	15

Table 6 Summaries of Article Elements At City level

Sl. No.	Authors and Refereed / Not Refereed	Case Study Area and Country	Samples (n)	Parameters / Variables	Method of Assessment	Assessment of a route/facility/ route and facility	Smart System Enabled	Main Focus	Validation	Study Type	Accessibility measure
1.	Lewis et al [52] (Not Refereed)	Cardiff, Edinburg, Leeds and Hitchin (Hertfordshire), U.K	Access auditor and a disabled individual	Physical Access variables not discussed.	Quantitative and Qualitative	Facility	Not Enabled	An audit of current level of physical access barrier to services for disabled people	Access auditor and disabled individual	Cross Sectional	Infrastructural measure

2.	Linda Beagle [56] (Refereed)	Northampton U.K	Wheel chair users types	Slope angle, Surface types, Dropped Kerbs	Quantitative and Qualitative	Routes (Side walk)	Enabled (GIS based and later web enabled)	A Decision support system for identifying barriers in urban landscape for different categories of wheelchair users	Application and interface had been Tested with wheelchair users.	Cross Sectional	Location and Infrastructure
3.	Harolod Holone [51] (Not Refereed)	Halden, Norway	Wheelchair users	Uncomfortable to maneuver (roads with poor and confusing sidewalks), inaccessible (roads lacked sidewalks) and Good (relief from roads). Sidewalk/road Network and minutes	Quantitative	Routes	Enabled (Our Way Algorithm developed with the support of OSM server)	Collaborative pedestrian navigation system for differing abilities and preferences with the support of existing user feedback	Simulated the four tasks in the lab trails with the support of field trails and existing user feedback.	Cross Sectional	Time space measure and Infrastructure
4.	Irene Casas [58] (Refereed)	Greater Buffalo Niagara region, Western New york, USA.	Wheel chairs users, people having difficulty in standing, and walking, Cane users, Deaf and Blind	Age, Gender, License, Jobs, Student status, Occupation, Household Income, own/rent status, mode, number of vehicles with H/H.	Quantitative	Routes	Enabled (Arc GIS scripting language)	To assess the number of opportunities in an individual activity space and compare the level of access between disabled and non-disabled. (Social Exclusion)	Based on the travel diary data the users access to opportunities have been evaluated.	Cross Sectional	Location and Time space measure
5.	Ferreira and Sanches [57] (Refereed)	Sao Carlos, Brazil	Wheel chair users	Longitudinal Profile, Surface of Sidewalk, Sidewalk material, effective width of sidewalk, intersection	Quantitative and Qualitative	Routes (Side walk)	Not Enabled	An Index to evaluate performance of sidewalk and public spaces in urban road networks.	User evaluation of the routes	Cross Sectional	Infrastructure
6.	Wennberg et al [59] (Refereed)	Hasselholm, Sweden	65-79 years and Above 80 years	Physical Barriers (difference in level, uneven surfaces, drainage grooves and Kerbs), Orientation, Bus stops, Shops, Orderliness, Benches and Stairs, contrast/warning	Qualitative	Routes and facilities on the sidewalk	Not Enabled	To understand the perception and satisfaction levels of older people and planners view in municipality before and after implementation of legislative measures.	User evaluation of the routes and facilities on the sidewalk	Longitudinal	Infrastructure
7.	Jackson MA and Ralph Green [24] (2011) (Not Refereed)	Kensington, Melbourne, Australia	Three wheelchair users and one part time wheelchair user	Built Environment Infrastructure, Public and Commercial building, Private Dwelling.	Quantitative And Qualitative	Routes and Facilities	Not Enabled	An application of Universal mobility Index developed by Ralph Green by combining policy and built environment attributes in Kensington neighborhood.	User Evaluation	Cross Sectional	Infrastructure
8.	Rosenberg [60] (Refereed)	King County, Washington, USA	Wheel chair users and assistive devices like canes, walkers and wheelchair users (35 numbers)	Curb ramps, parking, lighting, weather, street crossing, sidewalk amenities and traffic.	Qualitative	Routes and facilities on the sidewalk	Not Enabled	To evaluate through perception study the barriers and facilitators in outdoor environment to physical activities among mid life and older adults to physical activities.	User evaluation	Cross Sectional	Infrastructure

9.	Pascal Neil and Zielstra [53] (Refereed)	Berlin, Riga and London	Wheel chair users	Sidewalk width, Steps, Steps height, Slope, Camber, Kerb, Curvature, Lighting, Landing/Crossing, General Access, Tactile.	Quantitative	Routes (Sidewalk)	Enabled	An algorithm developed for assessing the footway information for disabled people with special information and navigational needs	100 shortest paths were generated for sidewalk and street network and length was compared. Buffer comparison method – percentage of overlap shall be determined.	Cross Sectional	Infrastructure
10.	Pascal Niel [54] **(**Refereed)	Bonn, Germany	Wheel chair users	Slope, Width, Surface, Smoothness, Sloped Curb, Lighting.	Quantitative	Routes (Sidewalk)	Enabled	The city network generated through volunteered geographic information. The routes were computed based on impedance scores based on user preferences input and the standards of DIN. The reliability of the route is verified through individual weight with available length with total length.	Validation by two weighting methods, followed by Good child and Hunter Buffer method. Reliability of the computed routes also verified	Cross Sectional	Infrastructure
11.	Vale David [55] (Refereed)	Lisbon, Portugal	Wheel chair users and able bodied persons	Pedestrian Network, accessible network, number of building and activities reached.	Quantitative	Routes (Sidewalk)	Enabled (GIS Spatial Network Analyst)	It is used as a planning tool to assess and identify critical areas for wheelchair access in the city (Social Exclusion Studies)	Not validated by the users	Cross Sectional	Infrastructure

Table 7: Attributes of Barriers based on various aspects

S. No.	Aspects	Attributes
1.	Planning and Design of a space	Lack of curb ramps, dangerous curb ramp conditions, accessing destinations through parking lots, space limitation between vehicles in parking lots to embark and exit from cars, difference in levels, uneven surfaces, paving slabs, length and gradient of slopes, gravel, cobbles, gullies, drains, dropped kerbs not flushed, limited turning circle.
2.	Maintenance	Graffiti, littering, undulation of sidewalk due to driveways, potholes, cracks and debris.
3.	Law and order	Smoking, Crime, vandalism
4.	Lack of provision of amenities and implementation	Poor crossway markings, uneven surfaces due to trees and roots, no kerbs at zebra crossings, no commercial sign and baskets.
5.	Multiple use of a space	Parked bicycle, bicyclists sharing sidewalk
6.	Behavior related aspects	Fear of falling

Figure Captions

Figure 1: Routes, Barriers and Facilitator

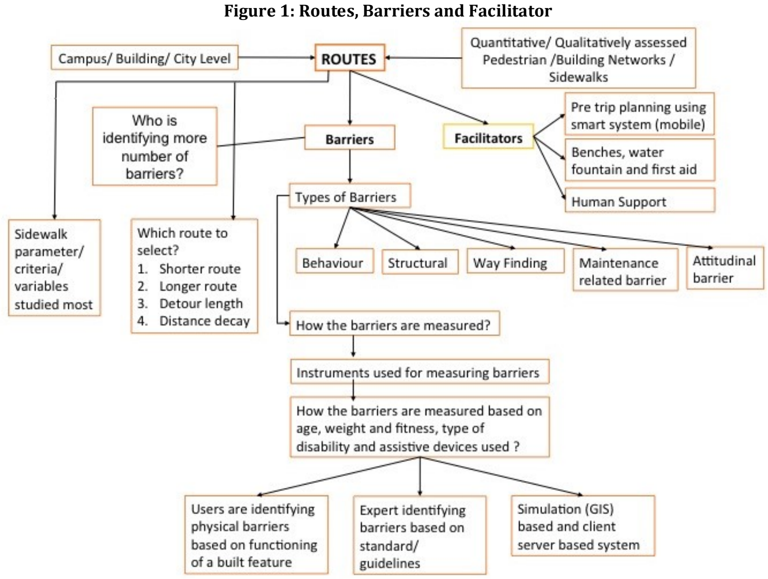

Figure 1: Routes: Barriers and Facilitators