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Assessment of Building Connectivity Within Multi-Storey Public Buildings Towards Adequate Circulation in Complexes of Abuja, Nigeria

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ABSTRACT

For a building complex to be user-friendly, it must possess one of the most important features of functionality, which is circulation. This for a public building complex is flexibility in movement from one building to another. This is because in such complexes no building is in isolation, hence the interaction between the building themselves and its end users. Absence of structural connections and visitors alike. These complications can reflect in terms of time and the effort it takes to move from one building to another. The study is aimed at deriving the significance of connectivity in complexes of public storey buildings in the capital city of Nigeria, Abuja. The derivative purpose of this research is to have a positive impact on the circulation pattern from one structure to another. In other to achieve this aim, primary data sources were employed. Structured questionnaires and observation schedules were also used to obtain data on physical observations, user perception and the nature of building connectivity respectively. In total 120 questionnaires were used and a 100% return rate was recorded. The study areas are six in number hence this translates to 20 questionnaires per study area. Also, the observation schedule used looked at 21 different issues in each study area. The data obtained was processed with SPSS and Microsoft Excel. From the results obtained it was understood that connectivity in public buildings hugely affects the efficiency and time management of the end users in such buildings. This study hence recommended that public buildings within complexes should be linked at all floors with well-designed, safe, and secured suspended walkways or sky bridges in other to facilitate building movement on the same floor.

1. Introduction

Public buildings serve the purpose of providing the civic environment with an edifice for communal, administrative, religion and recreational activities; nevertheless, their functional purpose of serving adequate circulation would not be over emphasized to meet to the population size of the public not minding their individual differences. Apart from the functionality purpose and adequate circulation, Public buildings should be secured enough to cater for security wellbeing of the populace. A good design of public structure should provide adequate space to meet up to their scope in which it is intended. (HM Government, 2006). Three factors must be considered in the design of public buildings; design must attain the criteria tenure of safety, healthy and sustainability. The reasons for these factors would not be far away from the fact that services are rendered easily when the design parameters are considered. Such reasons foster unity in the community as added variable to be considered when designing public buildings. (US General Service Administration 2004). Accessibility of public buildings should be considered as a unifying factor for various groups of users; the aged, physically challenged, less privileged and physical class in the society. Design parameters to be considered will not be far away from workable spaces, anthropometrics and functional

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connectivity towards been user friendly. (Californian Building Code 2013).

Building connectivity refers to the connection between two adjoining structures to effectively permit circulation. It is necessary to allow effective movement of individuals from one building to another especially when complexes comprises of multiple suspended floors and requires easy access and linkages. Movements are easily effective in higher floors of complex when adequate design parameters are considered to facilitate good circulation. Challenges usually occur when a complex has multiple buildings with numerous suspended floor without proper connection from one building to another, either through the suspended floor, ramp, stairs, lifts or escalator. This challenge is most seen where movements is required at the top floor of a building to another top floor of same complex. Building connectivity differs from modest connections in relations of usual open paths on the grounds of the complex, to compound connections joining buildings through roads and wide distance passages in urbanized countries. These are the two dissipations of building connectivity.

In Nigeria, quite a good number of civic buildings have building connections; shopping malls, secretariats, hospitals, schools and offices. The connections are inter linked in complexes in other to effectively improve circulation and provide swift access. Suitably planned building connection has numerous benefits. Humble paths on the ground provides easy walk ways for movement of publics in a logical manner. Absence of the walkways may warrant people to naturally decide where to follow leading to destruction of scenery and other structure or even access to restricted areas not open to passage (Oni and Bello, 2012). Simple connections on suspended floors proffers great functional circulation concept to complexes with more than two building structures. It is time saving as far as movement is concern and allows for the energy efficiency in man's quest for ease of doing work. Building connectivity denotes safety in terms of fire outbreak escape routes and provides optimization to natural lighting and ventilation into multiple building present in complexes. This reflects the links for easy movement of individuals to outside of the building.

In more difficult links as in Pedways and subways most especially through roads, this help in active circulation among structures that also save time. This helps in avoidance of people crossing the main road amidst heavy vehicular traffic there by improving human safety. Through this way, building connection have reached to the next level in advanced countries (Michael, 2007). A typical type of this connections does not have much restrictions on the movement of people. Their design is not just limited to buildings in complexes but rather goes along the avenues and city blocks where people find it more comfortable and safe to move. A design type of such connectivity are compound to the reality of professionals as the design teams that involved Architects and Engineers take in cognizance of structural stability more to the aesthetic feature. Examples of buildings that exhibit a type of the connection that characterized such a high density of public presence include; bus stations, railways, airport and other transport facilities (EESP, 2012). Such services are linked to one another or to civic structures in an organized way in other to simplify the movement of the people. An example is connecting a Bus station to a Train station, connecting a Train station to a Shopping mall and connecting a Train station to an Airport.

In various advanced nations the matter of building connectivity is a concern of law as it is obviously specified in their building codes that all edifices and civic facilities whose purposes is a key pull to the public must be linked to one another. This implies that holders of such structures need to ensure that their designs must reflect flexibility in connection to the next building.

2. Brief Review of Categories of Building Connectivity

Building connectivity are categorized based connections that are below the ground level which are also termed tunnel connections and connections that are above the ground level which can also be called suspended connection.

Tunnel connection; This type of connection is more reflected in highly populated cities that are immensely attracted by civic infrastructures of the likes of transportation, office and commercial buildings which imposes movement of the people to be difficult (Michel, 2007). The underground movement, even though it helps in limiting difficulties in movement of people, the traffic movement of people is sometimes unprecedented. This action constitutes a factor of human traffic since the movement are not usually exposed to the outside, it runs into millions of people moving and strategically parking their vehicles in sub ways and underground walkways. This offers an opening for certain of the human movement to be sidetracked to the next applicable building by joining it with an underground walkway. This diffuses the human traffic in diverse ways creating movement stress-free. An example is found in Toronto where fifty and above buildings are linked to an underground tunnel. Such of the buildings include; CN tower, Riply's aquarium of Canada, union station, two major shopping centers, six major hotels and a railway terminal (Marcus 2007).

On Ground Connection; this is basically placed as walkways linking two or more buildings (Collins, 2014). This is commonly found in both developing and developed cities of the world. Precisely, it is a connection between two buildings that is mostly designed for pedestrian movements with landscaped features that modifies the micro climate for comfort and quality air that humans breathe. This building connectivity could be exposed to the air or covered. When the connection is exposed, it safe guard one from mud and splits of water or rainfall spillage while further advantage

of covered connection shield the pedestrians from other climatic factors that are usually harsh to humans.

Above Ground Connection; the above ground connection is also referred to as the suspended connection. The connectivity can appear in various forms when considering the height of the building and how complex the link becomes. The circulation is such type of connection is also referred to as the skyway exist. It comes in different forms of suspension through passages, pedestrian bridges, and sky bridges. Most of the above ground connection occurs in city centres where is mostly characterized by storey buildings of great magnitude occupying complexes with sheltered and covered links to buildings and stretching towards major roads. This system of connection has a great advantage of making circulation flexible and easier with a good factor of saving energy and time. It provides safety to the pedestrian users because it is convenient in space through the traffic reduction and less noise absorption of footers and other source air and noise pollution (Sunny, 1973). Studies have shown the longest skyway to be that of Calgary, Alberta's fifteen plus walkway with a total length of 18km (Bellman, 2010).

3. Construction Materials and the building connectivity

When considering a material to be used for connectivity in buildings of complexes, certain factors have to be considered. Example of such factors include; flexibility, structural stability, strength, hardness and durability. Some of the materials that could have this elements that can be used for building connectivity include, wood, steel, reinforced concrete and plastic. Wood as a structural material is very light in weight when compared to other materials but has a lesser tensile strength when compared to its good compressive strength. The strength of wood is counted along its grain and the weakness against the grain (Hordley, 2000). In building connectivity, the harder the wood, the longer and wider the span of the connection. A hardwood timber with 115mm x 560mm sectional dimension can guarantee a connectivity of 11.5meter span at 1meter spacing.

Steel is a strong material with high compressive strength used in various construction work. It is widely used to cover a wide range of space for structural stability and building connectivity. It is an alloy of carbon with a content of 2.1% which constitutes its total weight and strength (Ashby and Jones, 1992). The strength in steel is highly needed for building connections to withstand a wide span and tremendous load. Steel combines a double advantage of both compressive and tensile strength. It also has a varied weight to strength ratio. This allows steel to size a very long span.

Reinforce concrete is another material widely used in building connectivity, it serve the function for both connecting floor and beams. They also perform the function of structural support in columns that support the connection. Reinforce concrete connection has a limited strength when compared to steel, however it is common with multiple support. Concrete as material is a good binding agent with a good compressive strength but has a very low tensile strength. The tensile nature of the concrete can be improved by reinforcing it with steel and other materials (Davis, 2009).

Reinforced plastics is a flexible material widely used in building connectivity. It is reinforced with polymer matrix of reinforced fibers to become a composite material used in building connectivity. (Smallman, 1999). This is one of the commonly used material in building connectivity. The flexibility factor of reinforced plastics makes it a very easy material to be molded into different shapes that would accommodate various components and shapes of building connectivity. The flexibility function of fixing into complex shapes allows it to be used in the International Space Stations (ISS). The reinforced plastic comes in different variety which are used in different components of carbon fiber, glass fiber, aramid and fiber material. (Erhard, 2006).

4. Methodology

The research methodology captured the assessment on the behavior of end users in selected public building complexes in Abuja, the capital city of Nigeria. The occupant's behavior on the building use gives a primary data source of preferences to their type of work and type of the building selected. To establish a statistical relationship between the variables, primary data collection method was deployed. The use of structured questionnaires and observation schedules were administered through a sample of 20 questionnaires per study area which amounts to a total of 120 questionnaires issued to respondents. There was a 100% optimal return rate for the questionnaires which produced a fit prospect of reflecting the real position on the ground. The questionnaires were design with respondents' box to thick where necessary, the applicable answer to each question asked while the authors ticked the guideline against the observational scheduled designed to reflect the reality on ground. The identified selected buildings within the complex were sampled based on the following types of public building; commercial, medical and institutional buildings. A total of 376 buildings were pointed out, of which 18 were identified to have a well-designed connectivity reflecting a standard form of public building connection. Six buildings were pin pointed for data collection using 1:3 ratio base. The six extracted buildings in Abuja include; National Hospital, ABM Plaza, National Raw Materials Research and Development Authority (NRMRDA), Head of Service Office, Federal Capital Development Authority (FCDA) and Federal Secretariat.

5. Data Analysis and Discussion of Results

Table 1: Showing number of buildings in the complex

Building Complex	National Hospital	ABM Plaza	NRMRDA	Head of Service	FCDA	Federal Secretariat
Number of Buildings in the Complex	12	2	3	5	4	3

Researchers' compilation, 2023.

The information portrayed on table 1 are figures gotten from the observation schedule. The number of buildings identified in each sampled complex is a reflection of the connection and relationship of building to building circulation. The observational schedule identified the National Hospital (Plate I.) in Abuja to have the highest number of buildings within the complex. This is connected to the reason that its design is conceptually dispersed, a common design concept found within the upcoming nations.

Plate I. National Hospital

Plate II. Head of Service office connection

Researchers' compilation, 2023.

The National Hospital is a government owned medical facility located in the city center of Abuja. The complex consist of twelve number of buildings interconnected by each building to serve for circulation and efficient work productivity within the end users. The ABM Plaza (Plate VII.) is owned by a private individual. It is a commercial complex designed for shopping and other business transaction located in the central area of Abuja. The complex comprise of two buildings, and each building consist of two wings. The two buildings within the complex are linked by a suspended uncovered connection linking the two wings. The National Raw Material and Research Development Agency (NRMRDA) as indicated in Plate VIII is a federal government agency, it consist of three buildings all linked by two connections at three storeys with two suspended floors. The building has a design phase that could be connected to all floors. The federal head of service office (Plate III and IV) is also located in the city center of Abuja. The building is a huge complex containing three structures with few of the tallest buildings in the city. Their highest point is categorized by 12 storeys with 11 suspended floors, which gives reasons for the presence of five connections at different levels of the complex. Plate III is The Federal Capital Development Authority (FCDA) complex which consist of a single connection containing four structures. The ground floor serve the space for passage because it is open for both human and vehicular traffic while the first and second floor is used for connection to ease circulation from one building to another. The Federal Secretariat Abuja (Plate V) is one of the earliest built complex in the city. The complex houses three structures with one structure consisting of two high rising towers.

Plate III: Head of Service Abuja

Plate IV: Open Connection at Head of Service

Plate V: Federal Secretariat Connection

Plate VI: Covered Connection FCDA

Plate VII: ABM Plaza Open Connection

Plate VIII: NRMRDA Connected from other sides

Plate IX: Connection in National Hospital

Plate X: Connection at National Hospital

Researchers' compilation, 2023.

Plate IX and X are two views of connections in the National Hospital. It has a 3 meters wide connection but absolutely inadequate considering the size and magnitude of the structure.

Table 2: Showing Various Frequencies of Connections within the Six Complexes

	National Hospital	ABM Plaza	NRMDA	Head of Service	FCDA	Federal Secretariat
Number of buildings in the complex	3	4	4	12	3	11
Number of connections in each building complex	3	1	2	5	2	5
Width of connections in various complexes	3	2	2.5	4.5	2.5	4
Number of floors in connections	2	1	3	4	3	11
Lengths of connections observed	10	5	4	15	8	16

Researchers' compilation, 2023.

Table 2. Indicates the various connections within the complexes sampled. Some of the indices that determine the number of connections in a building complex involves the height and number of buildings in that complex. Some of the factors may differ in terms of width and work function of the particular complex. It is expected that a complex of more than two storeys should have a minimum of two connections but reverse is the case for ABM Plaza, a four storey building with just a single connection. A better representation is noticed in NRMRDA and FCDA buildings with same characters of building size, area, height and number of users exhibiting a better connection of two links per each building floor within the complex. This character have made circulation very easy in both buildings of NRMRDA and FCDA. An inadequate circulation pattern is noticed in the National Hospital Abuja. It has a bigger magnitude of size and expanded at larger area space but characterized by only three connections. It expected that the building should have more than three connections in other to ease the movement from one building to another. Though some ramps where observed at the ground floor easing movement of people, but it still require a good number of suspended floor connection to easy up traffic, especially considering movement of patients and other bigger dialysis machine that require easy flow at the same floor. The Federal Secretariat and Head of Service Office have been identified to have highest number of buildings in the complex, 11 and 12 buildings respectively. They are also noticed to have the tallest set of buildings with the highest number of five connections per each link of suspended floor to a building.

The determinant factor for the width of connection in a particular structure include the size of the structure, the function of the structure, population size of occupants and the number of connections considered within the structure. This becomes necessary because the width of the connection of a building carries along the highest percentage of human and material movement. The width of connections from the Head of Service Office and Federal Secretariat has the widest connections of 4.5 and 4 meters respectively. This means that the two buildings have the most occupied users in a particular unit of each structure. This denotes that the width of connection of any structure should be directly proportional to number and size of the occupants in the building. NRMRDA and FCDA are relatively proportional to their sizes and a width of 2.5 meters. This is however not proportional to size and width when considering the National Hospital and ABM Plaza. National Hospital Abuja is also not proportional because of the 3 meters wide. But it can be made proportional when the width of connection is increased to 4 meters and above. Subsequently, the ABM Plaza should have more than one connection. To achieve easy circulation and movement of materials in any building connection, the width connections need to be proportional to the structural size and occupants of such a structure.

Taking into consideration the prevailing situations, it is observed that the sequenced number of floors in a particular structure does not guarantee nor reflect the number of floors of connections. In reference to NRMRDA, Federal Secretariat and FCDA, it identifies equal number of floors within its connection while ABM Plaza, Head of Service Office and National Hospital Abuja does not have equal number floors within their connections. National Hospital

consist of two floors for the connection when compared to the three connections for the main building. ABM Plaza has just one floor of connection compared to the four floors for the main building. Head of Service Office consist of four connections when compared to twelve floors for the main building. The frequency of floor connection is the most effective factor of building connection, notwithstanding the width is more considered as an important factor when compared to the length in providing effective circulation and human traffic.

6. Summary of Results

Indications from data collected have revealed the very importance of building connectivity in storey building of complexes. Circulation through multi-storey building has become a paramount design element that facilitates ease of human movement and other conveyance of materials that require installation and linkage from one building to another in the same complex. The returned questionnaires have justified the observation scheduled indicating the link

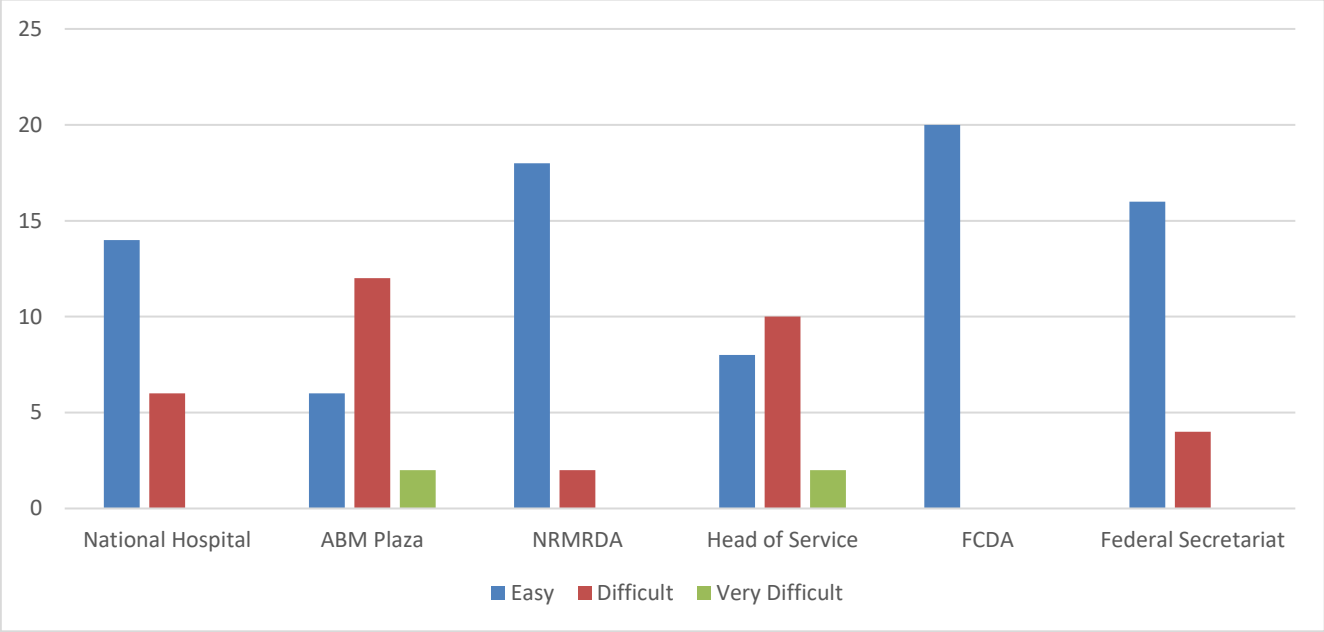

Figure1: Indicating Ease of Access and Movement to other Building within same Floor

Researchers' compilation, 2023.

Results from Figure 1 indicate that movement in the FCDA complex is easier from one building to another on the same floor compared to other complexes. The ABM Plaza identifies more difficulty in movement, this is not unconnected to the point that the structure consist of only one connection located at the first floor and unsheltered. Other indices in responds to movement indicates very difficult movement from one building floor to another floor in the Head of Service Office and ABM Plaza. The Head of Service Office consist of 11 floors while the connectivity within buildings starts from the ground to the fourth floor. This implies that movement to other buildings from fifth to eleventh floor will require individuals to come down to the fourth floor before interconnectivity become possible. Movement from one building to another at the Federal Secretariat complex has been observed to be very easy and effective due to the presence of one connection linking all the floors in the building.

between height of storey and the number of buildings within a complex. This implies that the height and number of building in a building complex reflects the number of building connection needed for that particular structure. Notwithstanding, the space in place between the buildings is a design parameter in ensuring an adequate building connectivity. To further discuss on the sampled complexes in terms of number of buildings, the National Hospital Abuja consist of the most frequency of buildings when compared to other sampled complexes. To refer to height of the sampled building complexes, the National Secretariat and the Head of Service Office consist of the tallest buildings with both having building connections but that of the Head of Service remains inadequate because the connection stopped at the fourth floor. Another inadequate circulation and connection is noticed at the ABM Plaza with only one connection linking the entire complex.

The space analysis of the various building connection was also analyzed based on the width and length. A 4.5 meters width was recorded to be the highest of all the sampled connections while 2 meters was recorded for the lowest. Head of Service Office has the highest of 4.5 while

the ABM Plaza has the lowest of 2 meters. The highest length was recorded on the Federal Secretariat with 16 meters and the lowest from NRMRDA with 4 meters.

The physical characteristics of the connections were discussed based on the inception of the design concept. The sampled complexes were designed along their connections. They connections were attached to the building right from the design stage to the completion stage except for the ABM plaza that the construction came as an afterthought consideration. Observation scheduled and the questionnaires have identified the material used in building connection to be strictly reinforced concrete. Even though, alternative materials were suggested to be steel and reinforced plastics. The connections categories of the floors were noticed to consist of suspended floor connection and ground connection. The suspended floors connections were noticed to be the covered connections that provided shelter except for ABM plaza that was unsheltered, possibly because it was an afterthought construction. Other sampled building connections have a continuous support system identified to be the construction technique while NRMRDA and ABM plaza consist of simple two end support. The time interval of using connections and other means of movements shows that 170 seconds is required for Head of Service which becomes the highest when compared to 40 seconds from the FCDA movements.

The resultant effect of occupants' behavior from obtained questionnaires reflects the number of respondents per floor to users function. The number of users by floor is determined by the function in which the floor was designed for or allocated. A floor function that consist of a conference room or meeting room is categorized by traffic at peak period while office spaces, consulting rooms, corner shops would not actually involve heavy traffic. Therefore, the more a floor is populated, the higher the responses. In response to ease of movement in other to achieve adequate circulation, FCDA occupants gave a more positive reply because of the good number of connections they have while the ABM plaza gave a negative response because they have only connection linking the plaza to other buildings. The general response from all the sampled study areas accept the fact that building connectivity brings about efficiency of service delivery to their places of work and businesses. They necessitated that, the more the number of building connections in a complex, the more the productivity of the users.

7. Conclusion

The general concept of building connectivity is circulation functionality. The process in achieving this purpose is guided by the routine articulation of the various elements that brings about easy flow of human movement and material conveyance from one building to another. The building as a machine functions in enveloping the human and non-human for shelter and productivity. Furthermore, shelter would be more effective when the circulation pattern in every building envelope is given due consideration. The more the building has an easy flow of activities, the more conducive the building becomes. To relate building connectivity with storey buildings and complexes, the population of occupants, length and width are important tools to consider when designing and constructing any form of connection. These factors are attributed to the data collated from the study area. The type of building connectivity and the floor ratio has a direct contact to user's population and purpose of the building. While reinforced concrete was mostly used in the building connections in Nigerian, other materials like hardwood, steel and reinforced plastics can stand in for reinforce concrete. Materials used for any type of building connectivity must be of good strength, weight and spanning a good length and fire resistant.

Recommendations

1. Spacing should be an integral part of designing a building complex. This becomes necessary in other to allow proper planning of movement towards building connections within the building complexes. The more sufficient the dimensions are considered between the complexes and the buildings, the better the connection to have easy flow of circulation. Adequate spacing in such consideration provides the entire complex with economical connection, adequate lighting and ventilation.
2. Location and form of building complexes should be considered when designing the structure. The positioning of the building complex should be zoned to a populated function where the users of the building structure would have direct link to various connections in other to enhance accessibility to various moves and exist. The form of the building should be harmonious and conceptually conforming to the design morphology. By such consideration, safety and security would be effectively attended to.
3. Building connections should be linked along every suspended floor of a storey in other to avoid coming down from highest points of storey to link with terminated connection at beginning or middle floor.
4. The width of building connectivity should always be directly proportional to the size of the buildings in the complex, population of users and the anticipated traffic from materials and human beings. This factor helps in the judicious use of time to have effective service delivery in any type of building complex.
5. Building connectivity should be initiated in the first stage of the design so that it would be incorporated along every construction stage in other to have a structurally stable connection and to avoid an afterthought design. An afterthought design always comes with distortion which does not give a good function and form to a building connection.
6. Materials to be used in a particular type of building connectivity should be analyzed alongside the span between the buildings to be connected, the materials used in building construction and the weight (load effect)

of human and material. Steel is a good material that can span a wide distance without multiple support while been structurally stable. Reinforced plastics and aluminum are lightweight materials that are structurally stable and can be used likewise.

Stepped and ramped connections should be discouraged in other to justify the presence of the physically challenged towards easy movement. To further acknowledge the physically challenged, horizontal connections should be adhered to, or a gentle slope should come along with the floor.

References

Her Majesty's Government, (2006). Better public buildings for architecture and the department for Culture, Media and Sports, London. Retrieved from www.planx.com on the 2nd Nov.2023

U.S General Service Administration (2004). *Facility Standards for the Public Building Service.*
Retrieved from www.gsa.gov on the 5th December, 2022

California Building Code, (2013). Materials and Construction. 1(5), 22-26

Oni, T.O., Bello, M.O. and Oni, A.O. (2012). Forecasting demand for office spaces in Ikeja,
Mediterranean journal of social sciences. 3(1), 7-9

Michael, B. (2007). Extension of indoor walkways into the public domain: A partnership experiment paper delivered at ACCUS conference, Athens Greece.

Economic, Environmental and Spatial Planning (E.S.S.P.), (2012). *Sky bridges policy, draft for public participation, city of Cape Town.* Retrieved from www.capetown.gov on 6th October 2023

Marcus, S. (2007). The Ryersonian Ryerson university of journalism press, September (2007)

Serge, S. (2014). 8 Urban Design Strategies, Tianjin, World Bank Seminar on Todd

Sunny, V. (1973). Carbon Monoxide Dispersion in Down Town Spokane. *Eslinc, USA, United Nation Environment Program (UNEP), (2011).* Building for the future, Nairobi Kenya,Union publishing services

Bellman, E. (2010). Mumbai Builds Miles of Elevated Walk Ways, Yellow Caterpillar Huge Mistake. Retrieved from www.wsj.com/articles/SB1000 on 8th Nov. 2014

Hoadley, R.B. (2000). Understanding Wood: *A Craftsman Guide to Wood Technology.* Tounton Press. Newton, Connecticut.

Ashby, M.F. and Jones, D.R. (1992). Engineering Materials 2, Peregmon press, Oxford

Davis, U. (2009). Physical Design Frame Work, retrieved from dcm.ucdavis.edu/…/index… on 25th October, 2023

Smallman, R.E. and Bishop, R.J. (1999). *Modern Physical Metallurgy and Material Engineering,*
6th edition, Butterworth-Heinemann, London

Erhard, G. (2006). Designing with Plastics, Hanser publishers, New York