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ACCESSIBLE DISTANCE MEASUREMENT USING THE GT METRIC GRAPH

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Abstract
This paper describes a tool for measuring accessibility distances within and through building spaces. When we assess a certain building design, we should evaluate the ease of access from one point to another. Metric distance is important because it is one of the determinants of ease of use, along with space width, stairs and complexity of route. If we can measure the distance as well as check some aspects of the accessibility of a certain circulation path, we can call it an accessible distance measurement. We developed a computational method of accessible distance measurement based on a length-weighted graph structure using a given building information model (BIM). It is called the GT Metric Graph and has been implemented as plug-in software of Solibri Model Checker (SMC). It checks all paths in a building from a start to a target location. This paper focuses not only on its implementation but also on other intrinsic aspects that need to be considered in terms of accessible route. It addresses accessibility and metric distances based on consideration of ADAAG using an example test model.

Introduction
We introduce a method to measure metric distances within building spaces. Metric distance is one of the fundamental determinants of ease of use in terms of accessible building design. Our focus is on two particular aspects of design: metric distance and accessibility. We call this the accessible distance measurement, and we provide a computational method for it using the GT Metric Graph (Georgia Tech Metric Graph) structure for a given building information model. Even though distance is one of the basic required factors when we deal with accessibility, (Church, 2003) it is not easy to determine an effective measurement method. The purpose of the GT metric graph is to measure the distance within spaces by precisely calculated scalar quantity. It supports measuring distances by consistent computational methods, and it could be one of the major determinants for checking compliance with the requirements for accessibility in a specific interior space.

There were previous efforts for developing the method of compliance checking for the rules defined in the Americans Disabilities Act Accessibility Guidelines, (ADAAG) (Han et al, 2002) but the metric distance-related issues have not been commonly tackled by researchers, especially interior accessible routes within buildings. We provide a computational method for measuring accessible distances, with particular interest in considering clear widths for wheelchair accessibility.

GT Metric Graph

Basics for the Circulation Graph

We developed the GT Metric Graph following the question "how can we define people's circulation paths parametrically?", using a method for defining "good circulation paths." Our focus is on the building object's geometry and spatial connections, rather than the observation of free circulation of individuals. We have established specific factors for development reflecting human behavioral aspects of building circulation.

1) Building model-oriented circulation: The GT metric graph is a building model-oriented circulation model rather than an agent-oriented model. It represents the designer's expected circulation paths based on the loaded BIM model in the design review process. It is determined only by a given building model and its spatial adjacency, therefore it is particularly applicable to review in early design phases before construction.

2) Most efficient circulation: It is believed that people tend to walk along the shortest, easiest, and most visible paths. This is one of the key concepts for implementation. We assume that it might reflect the most frequently shown movement pattern of people.

BIM-enabled Circulation Graph

The GT Metric Graph is a computationally generated graph structure for a given building information model for visualizing circulation paths within spaces, and it simultaneously provides a metric distance measurement method. A building model can support multiple views of the data contained within a drawing set in 2D and 3D, and it can be described by its building objects or its attributes rather than mere building geometry. (Eastman et al, 2008 L Chapter 2) As a BIM-enabled application, the GT Metric Graph can be generated on top of the BIM model based on space objects and doors, vertical access objects such as ramps and elevators, as a spatial connection method. The conventional distance measurement method within spaces is a center line based measurement, but it has large tolerance value compared to the real human movement paths. Kannala's method for fire egress distance measurement also has the same problem, but it provides a precise computational method with consistency. (Kannala, 2005) In real-world buildings, there are many difficulties to determine the correct center of certain spaces, such as those with free standing columns, and human circulation paths do not follow a single route but take the form of a series of stochastic patterns. Thus we need a consistent method to determine metric distance within buildings in precise measurement, and the GT Metric Graph provides a solution.

Data Structure of Given Building Model

In this paper we assume that all the required information for the given building model will be provided by IFC[27] data. For graph generation, we need a specific view of the IFC model. We limit the scope of the graph derivation from the building objects to facilitating IFC data. Here we briefly list the key entities of IFC view for the GT metric graph.

1) IfcSpace and its geometry

[27] IFC: Industry Foundation Classes is an open and neutral specification for facilitating interoperability within building information modeling enabled applications. It has been developed and managed by IAI, (International Alliance for Interoperability) and most major BIM tools support the generation of IFC formatted building models. In this paper, the test model is generated by Autodesk Revit, and exports IFC data to Solibri Model Checker for graph generation.

2) IfcDoor and its geometry
3) IfcRelSpaceBoundary for acquiring spatial topology information
4) Vertical access objects: IfcStair, IfcRamp, etc.
5) Predefined agreement on the naming of objects, to distinguish circulation space, private versus public space, etc.

There are some building objects that are considered as obstacles for circulation such as walls or columns, but space objects are already defined by those kinds of physical objects' geometry data. Therefore we focus on space objects and their topological connectivity through doors.

Main Graph Elements

Below is a brief description of some key elements for comprehending how the GT Metric Graph is actualized on a given building model.

1) Buffer distance: Buffer distance is the minimum required distance between a wall and the top-center point of an agent. The default distance is half the length of a general person's shoulder width. Taking into consideration various agents (e.g. single wheelchair access or turning, two wheelchair passing, woman with a child, crowd, etc.) this buffer distance can be adjustable. If there is a space polygon, a buffer polygon could be generated by shrinking the space polygon using a given buffer distance.

2) Concave points: If there is an L-shape corridor, we can find 1 concave point and 5 convex points along the space boundary polygon. These are important vertex sets for the GT Metric Graph, especially concave points. Concave points are intermediate "coupling" vertices between two different door points.

3) Door points: These are two buffer-distanced points from the center of a door and perpendicular to its frame, in opposite directions. It is the most reasonable path to pass through a door. Door points are always a binary set for a door, and they make spatial connections.

4) Edges representing the circulation path: Based on the vertex set described above, graph edges are generated. Concave and door points are located on a buffer polygon of a single space object, and door points in the buffer polygon should be connected when they are simply visible to each other. When they are visually obstructed, this means that one or more concave points are generated, and the closest concave points will be the intermediate vertices between two doors in a space. In this way, space objects have their metric graph edges if a space has two or more doors, and it is naturally regarded as a circulation space.

5) Shortest path: Among the edges, and referring to the series of topological space sets, the shortest paths are chosen through the shortest path finding algorithm for representing a route path between two spaces.

Figure 1 compares the graph-based circulation representation methods between two spaces. The first one represents a topological connection between two spaces, the second one is the general center-line based graph, and the third one is the GT Metric Graph based representation. The topological graph is not suitable for calculating metric distances and for considering building objects' parametric conditions, but broadly used for representing spatial connectivity. The GT Metric Graph shows a measurable metric distance graph edges with more human-like walking trace than previous ones.

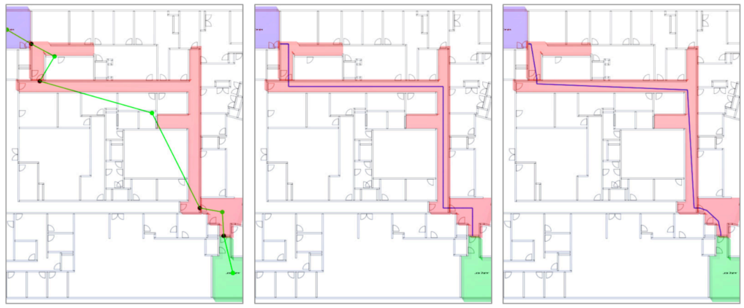

Figure 1 *Three graph-based circulation representation type examples. The third one is the GT Metric Graph.*

Graph-based Analysis for Accessible Routes

The definition of Accessible Route in ADAAG is "a continuous unobstructed path connecting all accessible elements and spaces of a building or facility. Interior accessible routes may include corridors, floors, ramps, elevators, lifts, and clear floor space at fixtures." (ADAAG, 2002) We note that the interior accessibility focuses on building objects such as corridors, floors, and clear floor space at fixtures. They are all space objects defined by bounding physical walls and structural columns. In other words, based on the BIM-enabled feature of the GT Metric Graph, space objects in a building could be easily gained as well as their spatial connectivity. First we use buffered boundary polygons from the space objects' boundary polygons.

Buffered Space Boundary and Clear Width

ADAAG defines the clear width for wheelchair access in an interior environment. Figure 2 shows some rules for the clear width of wheelchair access. It regulates the minimum width of circulation spaces such as corridors, and those rules can be implemented using the GT metric graph structure based on the buffered space boundary polygon approach.

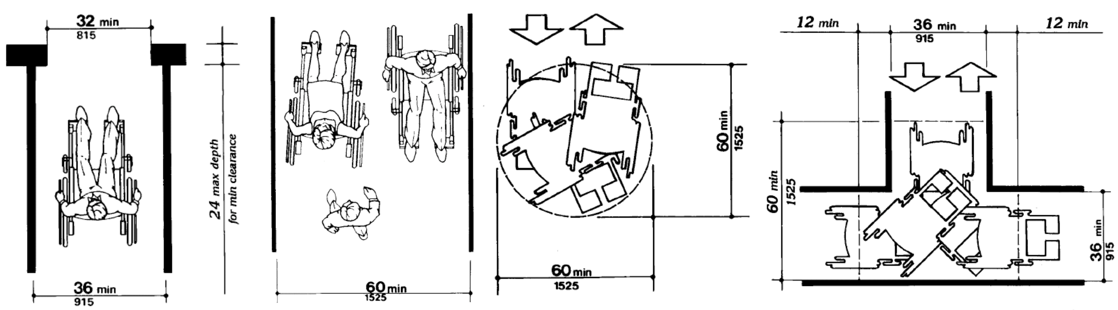

Figure 2 *Clear width definition for wheelchair access: 1) single wheelchair, 2) two wheelchairs passing, 3) turning, and 4) T-shape space turning (ADAAG, 2002). They are minimum 36, 60, 60, and 36 inches each.*

(Han, 2002) used the wheelchair geometry-based approach to accessible routes using motion planner. The motion planner aims at finding comfortable width along a route using the actual wheelchair's geometry. As opposed to this agent-oriented approach, our method is the building object-oriented approach to clear width checking. Figure 3 shows an example test model which has 21 space objects and 25 door objects. The image on the right indicates the space boundary polygons directly derived from its space object geometry. It is a test purpose model, and it has been tested in SMC using IFC format for representing the GT metric graph using different buffer distances. Our focus will be limited to demonstrating how buffered space boundary polygons determine clear width, and how metric distances are computed by the graph structure. Thus, we apply only two clear widths using buffer distances: 36 inches for single wheelchair access using an 18 inch buffer distance, and 60 inches for two wheelchairs passing using a 30 inch buffer distance.

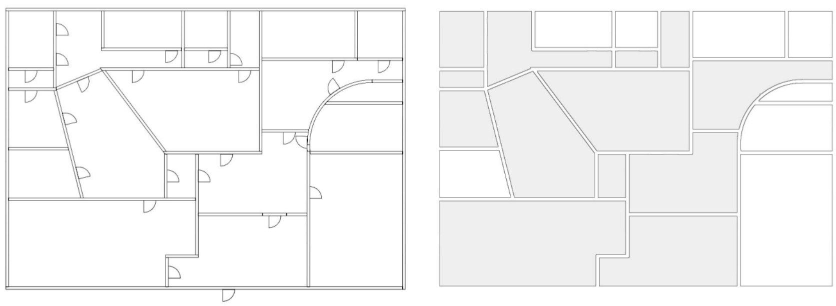

***Figure 3** An example floor plan and its space boundary polygons from the space object definitions. We assume that the spaces which have 2 or more doors are circulation space (gray colored).*

Figure 4 displays two different buffered space boundary polygons: applying 18 and 30 inches for checking two clear widths 36 and 60 followed by the rules shown in Figure 2. The graph operator implemented in SMC shrinks space boundary polygons, and computes relevant vertices to the metric graph generation: door points in blue color and concave points in red color. In this test, we found two result sets as follows:
1) 18 inch buffer test returns 53 door points and 27 concave points.
2) 30 inch buffer test returns 37 door points and 22 concave points.

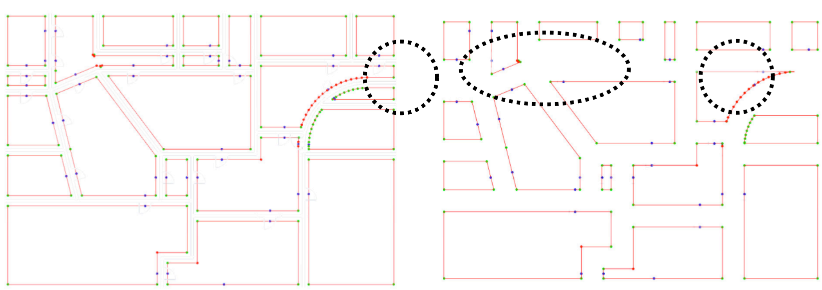

***Figure 4** Buffered space boundary polygons: 18inch buffer and 30inch buffer.*

This test model shows that it has compliances with single wheelchair access clear width. However, as shown in the right image of Figure 4, 16 door points and 5 concave points are missing when the 30 inch buffer is applied to the same model. As shown in the dotted circles, 3 buffered space boundary polygons are missing, and a narrow corridor disappears, thus those spaces may lose spatial connectivity in terms of the metric graph using 60 inch clear width for two wheelchair passing. This indicates that this test model has some problematic spaces in terms of two wheelchairs passing clear width.

Metric Graph on the Accessible Routes

Now the GT Metric Graph can be generated on the buffered space boundary polygons, using the door points and concave points. Figure 5 shows two computationally generated metric graphs for single wheelchair access and two wheelchair passing routes. The total generated edges are 107 and 88 each. Some edges are missing due to missing buffered space boundary polygons as shown in the dotted circles. Especially in the red dotted circle of Figure 5, it shows a missing corridor which is not satisfied with 60 inch clear width, and the two upper spaces lose spatial connectivity for two wheelchair passing. Any instance of circulation route is a subset of this metric graph, and as shown in Figure 5, route graphs will be different as a result of the difference of two buffer distances.

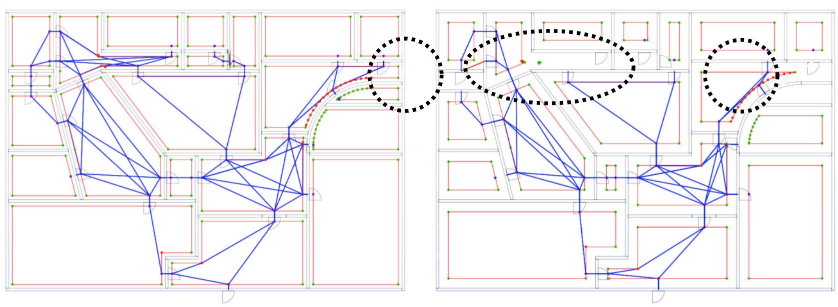

Figure 5 *GT Metric graph on the example plan. Some obstructed wheelchair passing routes found.*

Determining Accessible Route and Distance Measurement

Accessible distance is determined by the sum of gross length of the GT metric graph's edges of a route between two spaces. The route is accessible when the condition is satisfied that there are no obstacles which cut the graph edges between two spaces. If a route between two spaces has missing edges due to missing buffered space boundary polygons as shown in Figure 5 example, it is not an accessible route. The GT Metric Graph structure simply returns the result that a given route is accessible or not based on the clear width condition controlled by buffer distances. Accessible route could be determined as follows based upon the metric graph set, given two spaces, and a given buffer distance. An example of metric graph set is shown in Figure 5.

- Input: two spaces in a given building, buffer distance value, and metric graph set.
- Condition: the shortest metric graph route between given two spaces has contiguous edges.
- Output: True or False whether given parameters satisfy the condition or not.

The contiguity of metric graph edges is determined based on the spatial topology information and door points' binary elements containing spatial connectivity. No door points can be connected to each other if they are located on the network of adjacent space objects. Missing buffered space boundary polygons also omit some door points and concave points, thus an accessible route can be determined only in the buffer and vertex gathering phase of the graph generation process.

In case the route between two spaces is accessible, the metric distance of the route can be computed by the GT Metric Graph structure. As shown in Figure 6 examples, the metric graph edges between two spaces are retrieved from the metric graph set, and they are length-weighted graph edges. Thus the gross length of edges simply returns the accessible distance between two given spaces. Figure 6 illustrates two accessible route examples in the test model. The GT Metric Graph simply calculates the distance 66' 6" and 63' 7" each, in a single wheelchair access clear width condition.

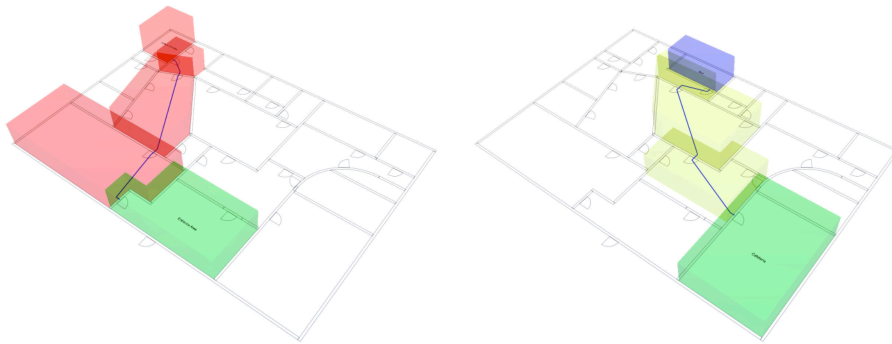

Figure 6 *Accessible distance measurement examples on the test model plan*

In these simple test examples are just part of accessible routes in the model, and total number of counts of non-repeated and shortest accessible routes are calculated by the equation for combinations without repetitions. In the test model example, when the buffer distance is applied 30 inch, total number of route is 210, and non-accessible routes are 74, followed by the GT Metric Graph calculation. Therefore 136 accessible routes could be found in the test model for two wheelchairs passing clear width. Examples in Figure 6 are two of them. If a building model has 1,000 space objects, considered as a general mid-sized office building, total metric routes between any of two spaces are 499,500. If we simply subtract the number of non-accessible routes from the total routes, it is the number of accessible routes of the building. The GT Metric Graph conveniently visualizes those circulation routes and their accessible distances using different buffer values in automation. In this way, it supports to compute accessible distances, followed by the fact that route condition is satisfied with clear width regulations using given buffer distance values.

Summary and Discussion

We proposed that a new BIM-enabled graph application for checking accessible routes within buildings. It also provides an accessible distance measurement method and a circulation visualization method considering various agents' situation based on the buffer values. Recently the term accessibility has become widely accepted in the broad area of design such that the design is accessible to all individuals, whether disabled or not. There is a set of issues within general accessibility described in the concept of universal design, but in this paper we captured and focused distance-related issues for accessibility and described a technological tool for checking accessible routes and computing their metric distances. It supports clear width checking while it is generated based on the buffered space boundary polygons, and continuous unobstructed paths are found within all space objects in a given BIM model. We have given an example test for demonstrating accessible route checking and distance measurement as well as the GT Metric Graph visualization on the model. We hope our approach to the accessible environment leads to further research and technological development in the future.

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