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A video game-inspired approach for a pedestrian guidance system within a railway station

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A Video Game-Inspired Approach for a Pedestrian Guidance System Within a Railway Station

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***Abstract*—This paper presents a novel routing system for guiding a pedestrian within a train station, accounting for aspects such as distance, crowd density, and the pedestrian's accessibility requirements. We achieve this by building a system that takes inspiration from the video games industry; constructing a Three-Dimensional model, annotating the model, generating a graph data structure, and performing pathfinding algorithms to establish the shortest path between two nodes. In particular, we make use of Three-Dimensional scanning technology to build a Digital Twin of Smethwick Galton Bridge station in the United Kingdom. We then use the spatial data to extract Two-Dimensional floor plans and perform Constrained Delauney Triangulation to compute a navigational mesh. The model then constructs the relevant graph data structure, on which we perform the A* Algorithm to determine the most efficient path between two coordinates within the mesh, where the efficiency is based upon both distance and the crowd density within the station.**

***Index Terms*—railways, pedestrian guidance, extended reality, passenger experience**

I. INTRODUCTION

Passenger accessibility has come to the forefront of progression in the rail industry. In the United Kingdom (UK), the government has pledged to make "rail more accessible and inclusive for all who want to travel" [1], with accompanying programs such as the *National Strategy to Boost Accessibility for Disabled Passengers* [2] and *Access for All* [3] paving the way towards accessible stations. Whilst these programs accomplish their goal in highlighting the issues, they do not provide tangible solutions; these are up to the rail industry as a whole to solve.

TravelXR is a project researching novel methods of guiding passengers through stations, using a combination of technologies that draw upon 5G infrastructure, Internet of Things (IoT) devices, and Extended Reality (XR) [4]. The project has three key stakeholders; BriteYellow, Bell Integration, and the Birmingham Centre for Railway Research and Education (BCRRE) at the University of Birmingham. In this paper, we present the work undertaken by the BCRRE into the Routing Engine (RE), developed as part of the wider TravelXR project to enable intrastation routing. Specifically, we focus on the computational aspects of the routing, selecting appropriate data structures and algorithms, with the intention of providing outputs to routing queries via an Application Programming Interface (API). Henceforth, we refer to this as the RE.

A. Previous Work

Spatial routing systems are not a novel concept, and there are a number of approaches to navigation guidance, including networks, hierarchical graphs, polygonal approaches, and building models [5]. Many of these approaches overlap, forming hybrid models [6]. The polygonal approach is of particular interest in real spaces, as it enables a larger degrees of freedom for pedestrians [7], [8], and allows the mapping of spaces of various shapes, size, and location with an identical approach [9].

One particular case is of this approach is within the video game and robotics industries, where developers apply a combination of these techniques to enable avatars to traverse the virtual Three-Dimensional (3D) spaces [10], [11]. The process generally begins by building the space itself, forming a 3D mesh constructed of polygons. Developers then annotate the model to declare navigable areas and obstacles by the avatars. Once this is known, the developers apply traditional pathfinding algorithms (such as Dijkstra's algorithm) to find the most efficient route between two points, where efficiency is often based upon the Euclidian distance between two nodes.

The difference between the virtual world and reality is the existence of spatial data; whereas video game developers construct their spaces as part of the process and have instant access to the data, we must map real objects. The relatively young field of Digital Twins, defined as real-time virtual representations of physical objects, is paving the way to allow easy representation of such objects and spaces. Matterport are one such company enabling this virtual mapping [12]. Within the rail industry, there have been previous attempts at building a Digital Twin of station environments. OpenSpace seek to build "cognitive digital twins for managing people flow" [13]. This work is important to allow for crowd flow modelling and infrastructure planning. However, their work has yet to provide tangible solutions to routing passengers directly through a station.

The authors would like to thank West Midlands 5G (WM5G) for funding the work undertaken as part of this paper.

B. Paper Outline

We split this paper into five sections. Section I introduces the motivations behind this research, and investigates prior relative work in this field. Section II describes the mechanisms and algorithms used within the RE, and formalises the process as a mathematical framework. Section III provides a use case for Smethwick Galton Bridge (SGB) station in the UK. Section IV discusses the contributions of the work, and outlines the impact within this project and the wider field. Finally, Section V summarises the work undertaken.

II. METHODOLOGY

The RE encapsulates the entire process of our work, from gathering the station floor plans to returning an appropriate route through the station. Figure 1 illustrates that there are three distinct stages pertaining to the RE, each made up of phases: *Data Preparation*, whereby we prepare the floor plans for the RE; *Engine Bootstrap*, which loads and processes the floor plan data into appropriate data structures; and the *Intrastation Routing Algorithm (IRA)*, which finds the fastest route between two coordinates within the station. Sections II-A, II-B, and II-C explain these stages respectively.

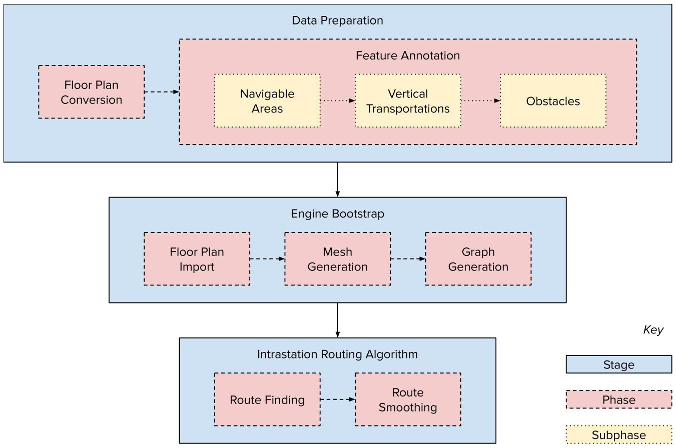


Fig. 1: The process of the Routing Engine.

A. Data Preparation

As per Figure 1, the Data Preparation stage consists of two phases: *Floor Plan Conversion*, where we we convert the floor plan to an appropriate file format; and *Feature Annotation*, whereby we annotate the Scalable Vector Graphic (SVG) floor plans to mark significant areas of interest within the station.

1) Floor Plan Conversion: For this project, we determined that the SVG format was useful for two reasons. Firstly, it stores data as points $p = (x, y)$, analogous to the coordinate system of the station. For each floor plan, we can determine a scaling factor σ that represents the number of points per metre, in order to scale the data to align with the real measurements of the station. Secondly, it is easy to manipulate and annotate, which holds significance for the next phase of this stage.

2) Feature Annotation: We split Feature Annotation into three subphases: *Navigable Areas*, which represent areas that passengers are able to traverse; *Vertical Transportations*, which represent methods of reaching other levels (i.e. elevators and stairwells); and *Obstacles*, which represent obstacles within a Navigable Area (e.g. benches and poles). Each feature is annotated as a polygon P.

Axiom 1 (Polygons): A polygon P is a Plained Straight Line Graph (PSLG) such that

$$P = (V, E), V = \{p_1, p_2, \ldots, p_n\},$$

where each point p_i is embedded within the Euclidean plane.

Axiom 2 (Graph Edges): For a graph $G = (V, E)$, there exists a set of edges such that

$$E \subset \{(u, v) \mid u \in V \wedge v \in V \wedge u \neq v\}.$$

a) Navigable Areas: To mark a Navigable Area, we draw a polygon P_α within the bounds of the floor plan. For any level, there may be multiple Navigable Areas F_α, such that

$$F_\alpha = \{P_{\alpha,i} \mid 1 \leq i \leq n\}, \tag{1}$$

where n is the number of Navigable Areas. It therefore follows that to see that F_α is also a PSLG.

b) Vertical Transportations: To mark a Vertical Transportation, we draw a polygon P_β that marks the area adjacent to the entrance of the vertical transportation method. Note that P_β must overlap a Navigable Area polygon $P_\alpha \in F_\alpha$; this helps to build the data structures in the Routing stage. To differentiate between Vertical Transportations within a station, we label each with a unique identifier of the form `type_id`. For example, we may mark the stairwells as `stairwell_0`, `stairwell_1` etc. As per Navigable Areas, we construct Vertical Transportations F_β as a PSLG such that

$$F_\beta = \{P_{\beta,i} \mid 0 \leq i \leq n\}, \tag{2}$$

where n is the number of Vertical Transportations.

c) Obstacles: To mark an obstacle, we draw a polygon P_γ around the obstacle. Obstacles F_γ are a PSLG such that

$$F_\gamma = \{P_{\gamma,i} \mid 0 \leq i \leq n\}, \tag{3}$$

where n is the number of obstacles.

B. Engine Bootstrap

The Engine Bootstrap stage is responsible for initiating the state of the program by constructing the internal data structures for use with the IRA. As per Figure 1, the it consists of three phases: *Floor Plan Import*, whereby we ingest the data into the software; *Mesh Generation*, whereby we perform Constrained Delauney Triangulation (CDT) [14] on the PSLG generated as part of the Floor Plan Import phase; and *Graph Generation*, whereby we generate a graph data structure that contains both the properties of the mesh and some additional data pertaining to the performance of the IRA.

1) Floor Plan Import: The first phase of bootstrapping the Routing Engine requires importing the annotations for each level L. A level L is a PSLG such that

$$L = \{F_\alpha, F_\beta, F_\gamma\}. \tag{4}$$

A station S consists of n levels, such that

$$S = \{L_i \mid 1 \leq i \leq n\}. \tag{5}$$

2) Mesh Generation: For each level L, we generate a mesh of n triangles T as

$$T = \mathrm{DT}(F_\alpha, F_\gamma) = \{(p_a, p_b, p_c)_i \mid 1 \leq i \leq n\}. \tag{6}$$

Furthermore, we compute the centroids of each triangle in T, forming a set C where

$$C = \{(x, y) \mid (x, y) = f(T)\}, \tag{7}$$

and

$$f(T) = \left(\frac{p_{a,x} + p_{b,x} + p_{c,x}}{3}, \frac{p_{a,y} + p_{b,y} + p_{c,y}}{3}\right). \tag{8}$$

3) Graph Generation: The graph for a level G_L consists of vertices V made up of the centroids c and a density to represent the passengers within the triangle polygon that derived this centroid, such that

$$G_L = (V, E) \mid V = \{v_i \mid v_i = (c_i, \rho), c_i \in C\}. \tag{9}$$

The edges E between neighbouring vertices are weighted based upon the aggregation of two time-based functions such that

$$E = \{(u, v, w) \mid w = g(u_c, v_c) + h(u_\rho, v_\rho)\}, \tag{10}$$

where g is the approximate time to traverse between the two vertex centroids such that

$$g(u_c, v_c) = \frac{\sqrt{(u_{c_x} + v_{c_x})^2 + (u_{c_y} + v_{c_y})^2}}{s}, \tag{11}$$

and h is the approximate additional time due to current passenger density, such that

$$h(u_\rho, v_\rho) = \omega_u u_\rho + \omega_v v_\rho. \tag{12}$$

For the work in this paper, we use static synthetic data to simulate crowd density. Within the scope of the wider project, we aim to utilise real density information to predict crowd flow and provide alternative routes within when necessary.

C. Intrastation Routing Algorithm

As per Figure 1, the IRA stage consists of two phases: *Route Finding*, whereby we determine the most efficient route between two points within the station; and *Route Smoothing*, whereby we smooth the route computed in the Route Finding phase.

1) Route Finding: To compute a route, we ingest two coordinates in the form (x, y, z) where z is the floor number. The first coordinate is the source, and the second coordinate is the destination. Firstly, we establish which graph vertex the coordinates are closest to. We then perform the A* Algorithm [15] to determine the shortest path between these two vertices, and return a list of edges.

2) Route Smoothing: To smooth the route R, we assume a complex polygon P_C constructed of the polygons that contain the route for each level. We then compute the centerline l of the Voronoi diagram of P_C [16]. (Figure 4 illustrates the difference between an original route and the smooth route, for the case study of SGB presented in Section III). For now, l includes the 'twigs', which are the offshoots connected to the edge of P_C. The project seeks to remove these in its next stages.

III. RESULTS

To provide deeper understanding of how the methodology works, we provide a case study of SGB in Section III-A. Moreover, Section III-B details performance results for the Python implementation of the RE.

A. Case Study

SGB is a split-level station in the West Midlands in the United Kingdom. It has three levels in total, with four platforms across two of those levels. The station is step-free, allowing any passenger to use the elevators instead of the stairwells to connect with any level. For this project, we received a floor plan (in Portable Document Format (PDF)) for each level. Figure 2 illustrates these floor plans for each respective level.

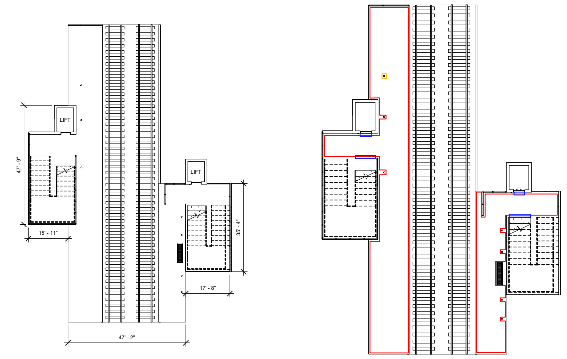
1) Data Preparation: Firstly, we converted the PDF files to SVG files. We then proceed to annotate the floor plans as per the Feature Annotation phase detailed in Section II-A2. Figure 2 illustrates these annotated features for each level.

2) Engine Bootstrap: To generate the meshes for each level, we utilise the CDT functions provided by the `triangle` package. Figure 3a illustrates the meshes for each level of the station. Furthermore, Figure 3b presents an abstraction of the graph determined from the coordinates of the mesh.

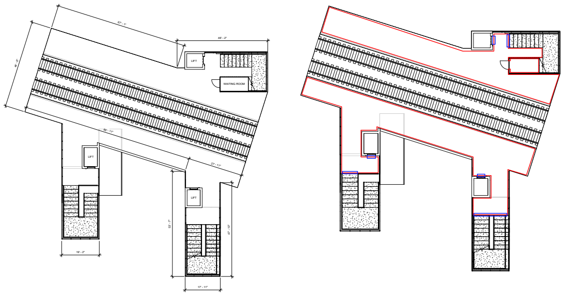
3) Intrastation Routing Algorithm: To test the functionality of the IRA, we selected two points within the station $(50, 7.5, 1)$ and $(1.5, 1.5, 3)$ to find a route between. Figure 4 illustrates this route throughout the station. In particular, Figure 4a demonstrates the plain route. Note the jagged nature of the route; this is due to the fact that the IRA plots the route via the centroids of the mesh elements, as per Section II-B2. To smooth the route, we take the Voronoi graph of the subset of mesh elements the route traverses through; Figure 4b illustrates this.

B. Performance

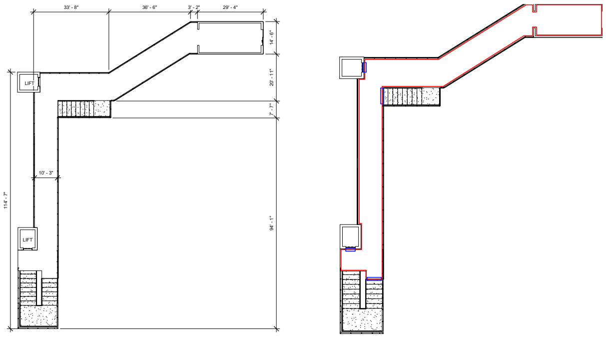
We test the performance of the Engine Bootstrap and IRA stages. Table I provides the specifications of the MacBook Pro used to run the work, and Table II provides the performance results of these two tests. We can see that each stage of the RE runs in a fraction of a second. The Engine Bootstrap, which requires running only when starting the RE, computes in $0.16\,\mathrm{s}$. Furthermore, the station object at the core of the RE has a total space of just $0.94\,\mathrm{MB}$, including all coordinates and graph information pertaining to the station.



(a) Level 1 of Smethwick Galton Bridge.



(b) Level 2 of Smethwick Galton Bridge.



(c) Level 3 of Smethwick Galton Bridge.

Fig. 2: Floor plans of Smethwick Galton Bridge. On the left-hand side are the unedited plans. On the right-hand side are the annotated plans: red annotations are Navigable Areas; blue annotations are Vertical Transportations; yellow annotations are obstacles.

TABLE I: Specifications of the MacBook Pro used for all computation.

Model	Brand	Apple
	Name	MacBook Pro 16” 2019
	Operating System	macOS 10.15.7
Processor	Model	Intel Core i9-9880H
	Speed	2.3 GHz
	Cores	8
RAM	Size	16 GB
	Type	DDR4
	Speed	2667 MHz

TABLE II: Performance for stages of the RE.

Process	Time (ns)	Clock Cycles
Engine Bootstrap	165,894,032	381,556,274
IRA	88,729,858	204,078,674

IV. DISCUSSION

The RE proposed in this paper is the first step towards a larger answer to guiding passengers within stations. We consider the advantages and disadvantages of the present implementation in Sections IV-A and IV-B respectively. We also address the impact of this work, and the research we plan to undertake in the future in Section IV-C.

A. Advantages

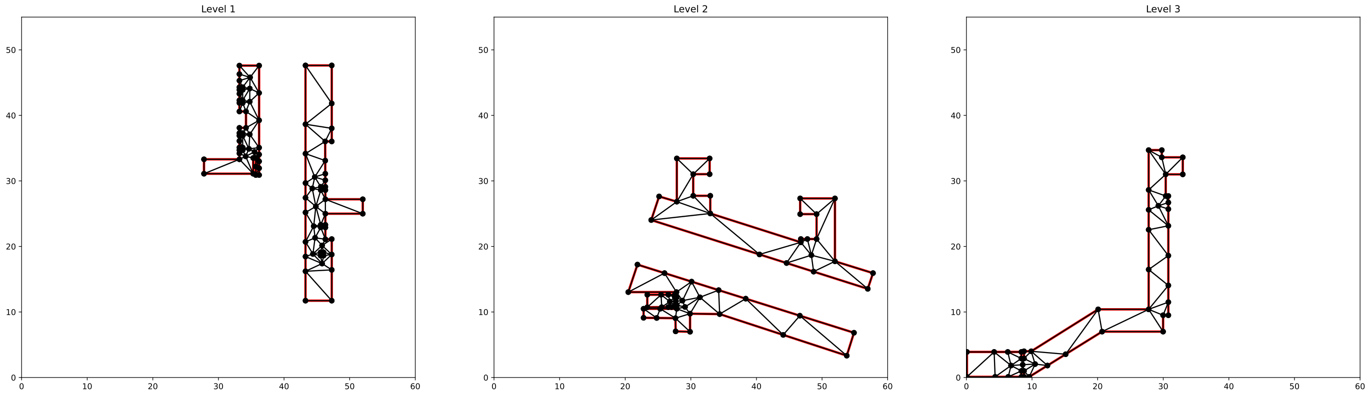
The obvious advantage of the RE is that intrastation guidance will become available for an array of different passengers. However, there are additional advantages pertaining to the mechanisms presented in Section II. The first of these is the annotation of SVG files within the Feature Annotation phase. This approach retains flexibility in deciding upon which areas of the station are navigable, and allows for built-in restrictions. For example, we may only annotate the Navigable Area up to $25\,\mathrm{cm}$ from the yellow safety, to ensure the IRA never instructs a passenger to go beyond this point. Furthermore, using the mesh system enables the RE to fit stations of various shapes and sizes.

B. Disadvantages

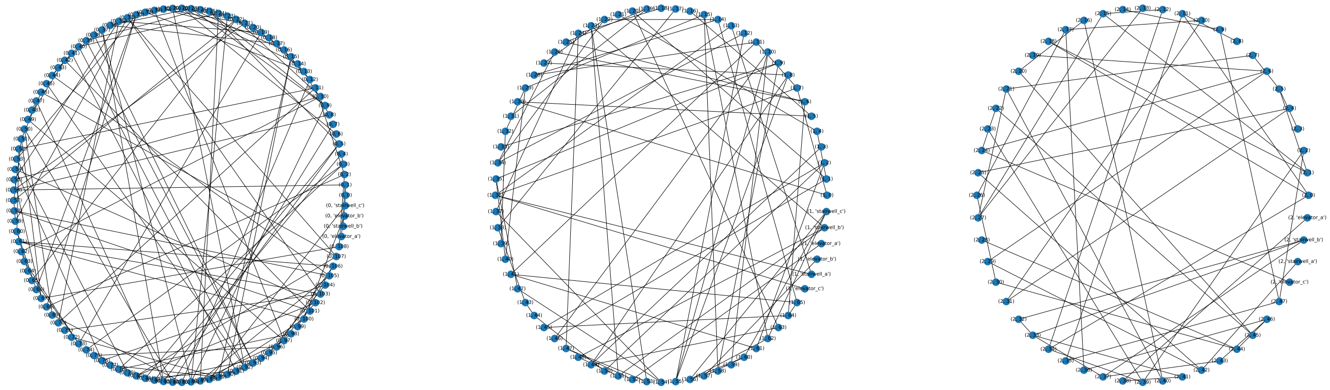
This research conducted as part of this project is ongoing; thus this paper reflects an evolving product. As such, there are several features requiring refinement. One such feature is the existence of centerline twigs, which are a natural feature of any Voronoi diagrams. In order to send a direct route based of the graph, we must strim these twigs from the structure. This is conceptually simple to achieve, and we are investigating pragmatic approaches to automating the process.

C. Impact and Future Work

The development of the RE shall benefit passengers by providing easy-to-use tools to navigate through stations. By the conclusion of this project, the work presented in this paper will evolve by addressing the disadvantages presented in Section IV-B and building the RE into a scalable, practical tool for real-world usage. We shall introduce the concepts of zones and points-of-interest into our data, allowing passengers to select appropriate facilities (toilets, coffee shops etc.) to route to. The RE shall factor in real-world density data as provided within the wider scope of this project, to enable alternative routes based on crowds. Furthermore, we will allow passengers to request multi-stop routes by updating the IRA. With the RE packaged as an appropriate enterprise solution, we will be able to develop additional technologies based on this work, such as an Augmented Reality (AR) layer to provide visual guidance aids passengers



(a) The generated meshes for Smethwick Galton Bridge.



(b) The graph for each level of Smethwick Galton Bridge. The graph for the entire station consists of these subgraphs, along with additional edges between the respective Vertical Transportation nodes.

Fig. 3: Data structures for SGB.

V. CONCLUSION

In this paper, we have presented our initial results for the RE we designed as part of the wider TravelXR project. Though we acknowledge that there is additional work required, we believe this work paves the way towards exciting new avenues of passenger accessibility. Taking inspiration from a purely digital industry has enabled us to build a model which works in the physical world with real-time efficiency and a high level of precision.

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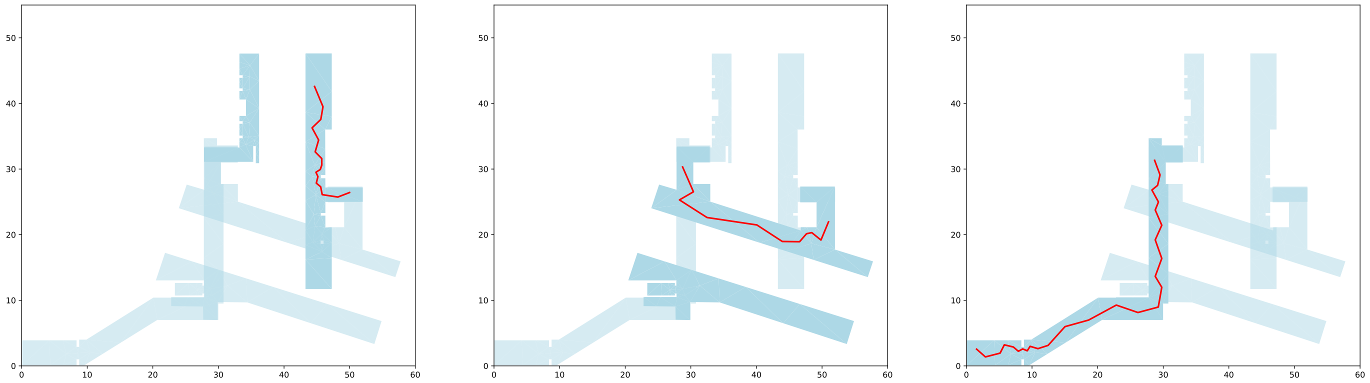
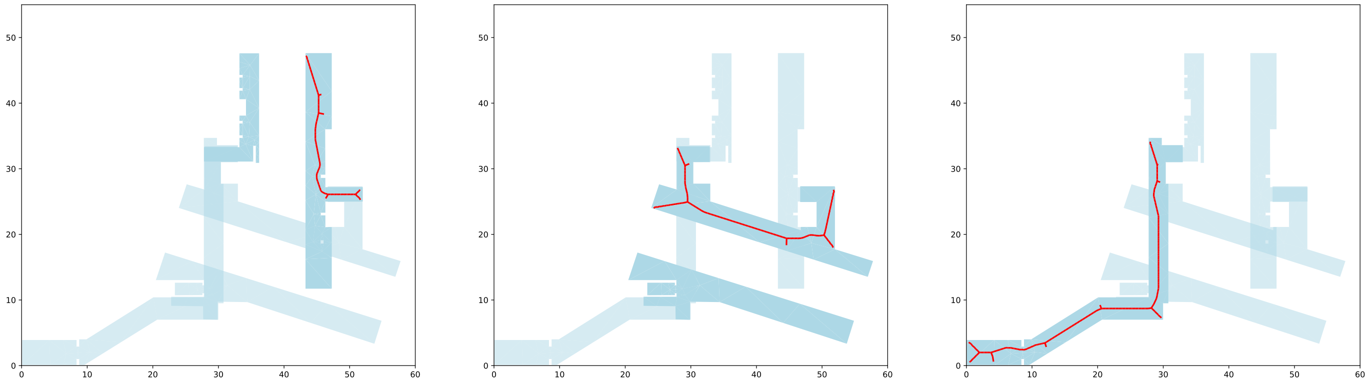


(a) An original route as computed by the IRA.



(b) A smoothed route, computed as the centerline of the Voronoi diagram.

Fig. 4: An example route within SGB.

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