Indoor Navigation: Navmesh Applied to Indoor Graph Creation

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Abstract: This paper explores the adaptation of the Navmesh algorithm, widely used in video games for pathfinding, to real-world indoor navigation. By applying polygon decomposition techniques, we generate routing graphs for complex indoor environments. Our results demonstrate that the algorithm is particularly efficient with orthogonal polygons, commonly found in real-life buildings, due to their structured geometry. We compare the performance across various polygon types and discuss optimization strategies for path naturalness and computational efficiency. This work opens pathways for practical applications in indoor navigation.

1 INTRODUCTION

Indoor navigation has become increasingly significant as spaces like shopping malls, airports, and museums grow more complex alongside societal advancements (Diakité and Zlatanova, 2018). Companies currently provide map services through terminals to help users locate destinations, but the next step involves real-time positioning and navigation within these environments.

This research focuses on generating graphs for indoor route searches. Presently, maps are manually annotated with location data (e.g., train stations, stores), and vertices are placed at fixed intervals, leading to dense graphs. Automating this process with polygon division algorithms could reduce workloads while offering tailored routing solutions based on different objective functions.

The main goal is to develop an optimal strategy for creating indoor navigation graphs using OpenStreetMap (OSM) data. This study adapts the Mesh Navigation (Navmesh) algorithm proposed by (Oliva and Pelechano, 2011), which partitions non-intersecting polygons into convex subsets. Although Navmesh is widely used in video games (Snook, 2000), this project applies it to indoor navigation.

Unlike road maps, where vertices naturally represent intersections and edges correspond to roads, indoor spaces present challenges. Placing vertices at regular intervals produces overly dense graphs, while positioning them at entrances/exits fails for non-convex rooms. A single vertex per room simplifies the graph but yields unrealistic routes. Navmesh, however, efficiently partitions complex spaces into routing graphs for realistic navigation, a technique adapted here.

The algorithm presented in (Oliva and Pelechano, 2011) has limitations: it omits the processing order for concave angles and assumes minimizing polygons as its goal without clear justification. This work explores multiple objective functions to assess the best approach.

The project begins with implementing the algorithm and conducting tests to evaluate its parameters, identify limitations, and optimize performance.

The remainder of this paper is organized as follows: Section 2 reviews related work, Section 3 details the Navmesh algorithm, Section 4 compares it to other methods, Section 5 presents results, and Section 6 offers concluding remarks.

2 RELATED WORK

While a significant amount of literature focuses on the modelization of indoor navigation graphs (Park et al., 2020)(Zhou et al., 2022)(Noureddine et al., 2020), fewer works address their automatic generation. The emphasis often lies on describing models rather than automating their creation. This gap highlights the need for more research into methods for automatic graph generation.

The division of polygons into convex components is not a new concept. It has been applied to nav-

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igation since the 1980s in robotics under the term meadow mapping, introduced by Ronald C. Arkin (Arkin, 1986). Theoretically, Lingas et al. (1982) showed that dividing a polygon without holes can be solved in $O(n^4)$ time, where n is the polygon's number of sides. Numerous other algorithms for polygon decomposition have been formalized (Hertel and Mehlhorn, 2006) (Keil, 2000) (O'Rourke and Supowit, 1983).

Since the early 2000s, the term Navmesh, often attributed to Golodetz (Snook, 2000), has gained prominence, particularly as a pathfinding tool in video games. Navmesh divides the walkable plane into convex polygons to form a simple graph, producing natural paths. Extensive research exists on Navmesh generation for multi-story terrains, dynamic 3D environments (O'Rourke and Supowit, 1983) (Berseth et al., 2015), real-time applications (Hale et al., 2021) and pathfinding (Brewer, 2019). However, applying such complex algorithms to 2D floor plans—simpler than video game environments—would be inefficient for this work.

While methods for manually creating efficient routing graphs exist (Yuan and Schneider, 2010) (Jensen et al., 2009), this study seeks an automated, straightforward approach. The algorithm from (Oliva and Pelechano, 2011), which offers polynomial complexity, has been chosen. Although generating Navmesh is NP-hard when minimizing polygons (Keil, 2000), the resulting solution, while not optimal, will be shown to be sufficient for our needs.

3 NAVMESH

In this section, the algorithm presented in (Oliva and Pelechano, 2011) is described, followed by an example that illustrates the creation of the graph through polygon division.

3.1 Description of the Algorithm

Let $A = (a_0, a_1, ..., a_{n-1})$ be the considered polygon. Let $B = (b_0, b_1, ..., b_{m-1})$ be the set of non-convex vertices of the polygon.

Definition 1 (Trigonometric and Anti-Trigonometric Direction)**.** *A set of points in $\mathbb{R}^2$ is in the trigonometric (resp. anti-trigonometric) direction if the points are in an anti-clockwise (resp. clockwise) manner.*

Definition 2 (Reflex Angles)**.** *Let α be an angle. α is a reflex angle if $\alpha > \pi$.*

The goal of the algorithm is to divide the polygon into a partition of convex polygons. The first stage

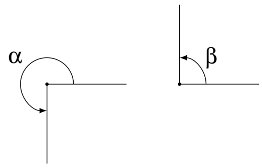


Figure 1: Examples of angles. α is a reflex angle ($\frac{3\pi}{2} > \pi$) but β is not ($\frac{\pi}{2}$).

involves identifying the reflex angles within the polygon. To achieve this, we iterate over the vertices in the anti-trigonometric direction. For each vertex a_i, we consider the triangle formed by a_{i-1}, a_i, and a_{i+1}. If the triangle lies in the external polygon (resp. internal polygon) and is in the anti-trigonometric (resp. trigonometric) direction, then vertex a_i has a reflex angle.

To detect these angles, we use the signed area of a triangle, calculated with the *shoelace formula* (Braden, 1986). The signed area determines whether the triangle is oriented in the anti-trigonometric direction (strictly negative), the trigonometric direction (strictly positive), or if the points are collinear (equal to 0). Using this formula, we identify all reflex angles in the polygon.

Once the concave vertices are identified, the algorithm generates a set of portals. These portals divide the vertex into two interior angles that are no longer reflex. We first describe the portal creation process and then analyze the impact of the order in which concave vertices are processed.

Definition 3 (Concave Vertex)**.** *A concave vertex is a vertex of the original polygon in which interior angle is a reflex angle. It is also called a* ***notch****.*

An example of a concave vertex is presented in Figure 1. α, which is a reflex angle, would be a concave vertex if it was an internal angle inside a polygon.

Let b_i be in B. In this part, we will suppose all indices are written modulo $n-1$. First of all, we have to find the interest area of b_i.

Definition 4 (Interest Area)**.** *The interest area of a vertex b_i is the interior polygon formed by the extension of its two adjacent sides, $e_{i-1,i}$ and $e_{i,i+1}$.*

An example of interest area can be found in Figure 2. In that interest area, any straight line coming from the vertex b_i will divide the reflex angle into two non-reflex angles. The object chosen by the algorithm, `i.e.` the object closest to the concave vertex inside of the interest area, will be connected to b_i, correcting his reflex angle.

Depending on the closest object, there are three possible cases:

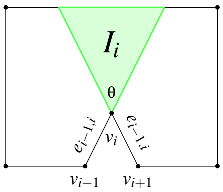


Figure 2: Interest area example. The interest area I_i, colored in green, is the interest area of v_i.

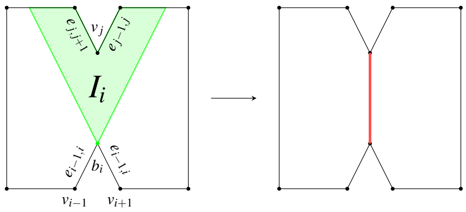
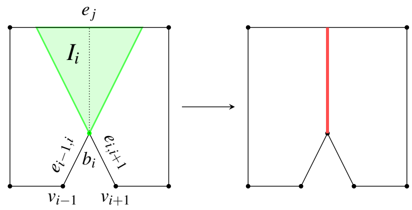


Figure 3: Portal from a vertex to another vertex. The closest element to b_i in the interest area I_i is v_j. On the right, the resulting portal connecting the two, in red.

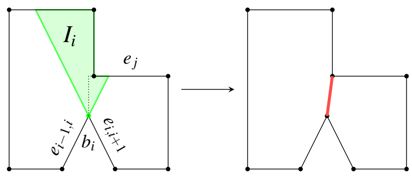
- if the closest object is **another vertex** c_j, the portal is simply a line between these two vertices. An example of these kind of portals is found in 3.
- If the closest object is **a side of the polygon** e_j, there are five candidates for the portal. The closest choice is its projection, but it is not necessarily in the interest area. We can also consider the two vertices incident to e_j or the two intersections of the interest area with e_j. Figure 4 shows all possible cases of this step.
- Lastly, if the object is **another portal** P_j, we connect the vertex to the closest extremity of P_j. If none of these extremities are in the interest area, we connect it to both of the extremities of the portal. Two examples are shown in 5.

We now know what to do with each concave vertex of the polygon. The question becomes: In which order are we going to consider the vertices?There are multiple possible orders:

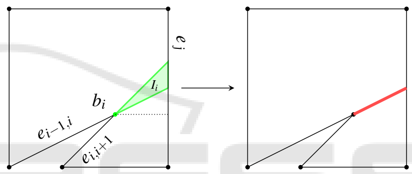
- **Random Order:** the random order is the first possibility. We think adding a random dimension could allow to better the performances instead of blindly following the same order for each polygon.
- **Trigonometric Order:** it would be interesting to compare the performances to a default order like this one.
- **Biggest (or Smallest) Angle First:** dividing the biggest angles first could give us bigger polygons from which to create the graph, but smallest interest areas gives us less choice, accelerating performance at the cost of some other characteristics.



(a) Portal from a vertex to a side of the polygon. On the left, the considered polygon, with b_i the current vertex and I_i the interest area. The projection of e_j is the closest object in the area, so the portal on the right connects the two.



(b) Portal from a vertex to a side of the polygon. The projection is not in the interest area; the closest object to b_i is the extremity of e_j, so on the right the two objects are connected.



(c) Portal from a vertex to a side of the polygon. The projection is not in the interest area; the closet object in the interest area is the intersection between the extension of $e_{i-1,1}$. On the right, the two objects connected.

Figure 4: Portals from a vertex to a side of the polygon.

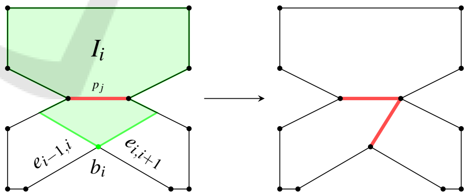


Figure 5: Portal from a vertex to another portal. On the left, we see the portal p_j is the closest object to b_i inside its interest area; both extremities are at the same distance, so we can chose one at random and connect it to b_i, which is done on the right.

3.2 Description of the Graph

From the division of the polygon in its different convex parts, we can create the graph by adding a node for every portal and creating a visibility graph.

Definition 5 (Visibility Graph in a Polygon). *Let P be a polygon. Let V be a set of nodes inside of the polygon. We create $E = \{(i \in V, j \in V), P \text{ covers } (i, j)\}$.*

The visibility graph for the nodes V in P is $G = (V, E)$.

The visibility graph contains an edge between every two vertices that can see each other; in other words, it contains an edge between every two vertices whose edge would be contained **inside the polygon**.

For our graph, we also add the condition that a portal acts as an edge of the polygon, `i.e.` an edge of the graph would not cross the portals. The next section contains examples of graph creation.

4 COMPARISON

In this section, we compare the Navmesh method to other commonly used approaches for indoor graph generation. Navmesh, while originally developed for video game pathfinding, has demonstrated significant potential for real-world applications, such as indoor navigation in complex environments. However, several alternative methods exist, each with their own advantages and drawbacks.

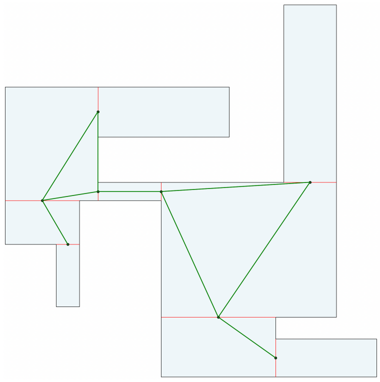
4.1 Equidistant Nodes

An alternative approach for graph creation involves covering the polygon with evenly spaced nodes and connecting adjacent nodes with arcs. As shown in Figure 6, the graph produced by Navmesh is notably less dense in comparison. While the equidistant nodes method is not inherently flawed, it results in overly dense graphs, which significantly increase the computational cost of finding the shortest path.

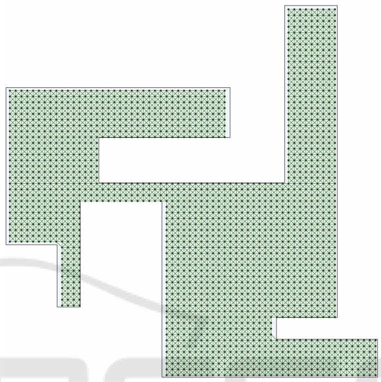
4.2 Delaunay Triangulation

Another way of creating the graph is using Delaunay triangulation (Delaunay, 1934). If we triangulate the polygon in that way, we can obtain different portals, and we can create the graph using the same method used for Navmesh.

Figure 7 shows us a comparison between these two methods. Density is no longer a problem, but one of our main goals is the "naturalness of the path", `i.e.`, that the path chosen in the graph should be as close as possible to what a human would do. We see in the Delaunay triangulation graph, the paths we could find would have a number of $\pi/2$ turns, but the graph generated by Navmesh would, intuitively, find more natural paths.



(a) Graph created by Navmesh.



(b) Graph created using equidistant nodes.

Figure 6: Comparison between Navmesh and the equidistant nodes method.

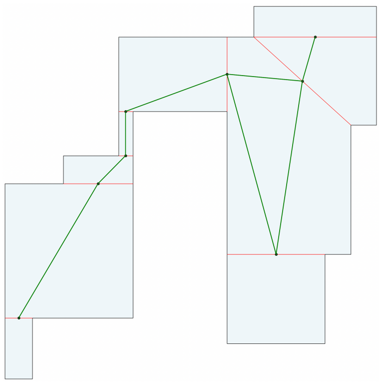
5 PRACTICAL RESULTS

5.1 Theoretical Results

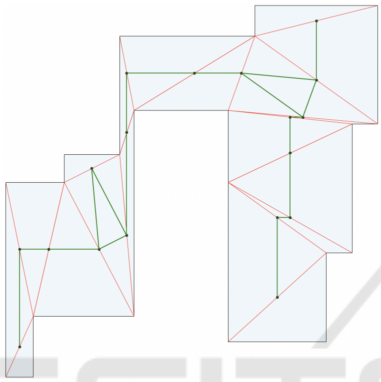
This section presents the obtained results. The algorithm has been applied to a set of three different types of polygons, each varying in size:

- Normal polygons - the algorithm was applied to randomly generated normal polygons to establish a performance baseline.
- Orthogonal polygons - these polygons are composed exclusively of 90-degree or 270-degree angles. Intuitively, orthogonal polygons are unions of rectangular shapes.
- Isothetic polygons - isothetic polygons are constructed using two distinct families of lines, where each family passes through a different common point, forming a skewed grid.

Figure 8 represents an example of both an orthogonal polygon and an isothetic polygon.

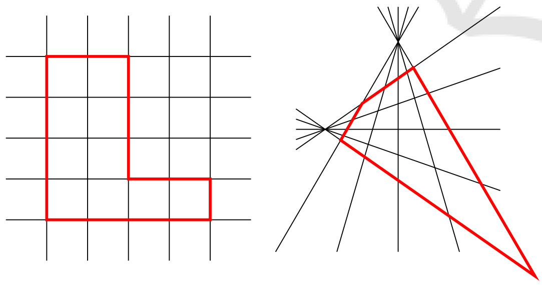


(a) Graph created by Navmesh.



(b) Graph created using Delaunay triangulation.

Figure 7: Comparison between Navmesh and the Delaunay triangulation method.



(a) (b)

Figure 8: On a, an orthogonal polygon, created from a quadrilateral grid. On (b, an isothetic polygon, formed from the grid created by two different families of lines passing through the same common point.

5.1.1 Polygon Generation

To create the test sets, a random number of polygons was generated using two different polygon generation methods. For the normal polygons, no restrictions were imposed, except for the exclusion of self-intersecting polygons. The used method allows for the generation of any polygon, including those with holes. The technique employed, known as Inward Denting, is derived from the article "Approaches for Generating 2D Shapes." (Hada, 2014).

Normal Polygons. The first step in generating normal random polygons involves selecting n random points, where n represents the number of vertices in the final polygon. The randomness of the polygon arises from these points, as the algorithm itself is deterministic and will produce the same polygon when given the same set of points.

Initially, the convex hull of the set of points must be determined. Several convex hull algorithms can be employed for this task, such as the Gift Wrapping algorithm (Jarvis march) (Jarvis, 1973), or Chan's algorithm (Chan, 1996). However, this article will not focus on this aspect.

The subsequent step, which is repeated until no points remain outside the polygon, involves adding the node that **modifies the perimeter the least**. For each arc of the polygon, the distance to each point is computed, and the point that contributes the smallest increase to the perimeter is added, while ensuring the polygon remains **non-intersecting**.

Orthogonal and Isothetic Polygons. For orthogonal polygons, we use the **cut and expand** method proposed in (Tomás and Bajuelos, 2004). The generation of orthogonal polygons begins with a 2×2 grid, where the grid is considered as a 2×2 square. From this starting point, the grid is expanded, and random sections are removed to generate an orthogonal polygon. The algorithm is divided into two distinct steps: the **expand** step selects a row and column of the grid for expansion, while the **cut** step selects one of the newly created areas to be removed.

When we generate orthogonal polygons on a grid like in our method, we simply create a grid which can be transformed into a matrix of size $n \times n$ with ones where the polygon has a square and zeroes where it does not. For isothetic polygons, we can then generate the isothetic grid and use that matrix as a template for that grid.

5.1.2 Results

Tests were executed on a server with 8GB of RAM and an Intel(R) Xeon(R) with 2.50GHz. The algorithm has been coded in Python; the importance of the results lies mostly on the comparison between performances, more so than on the performance itself.

To begin with, tests on three different types of polygons, described above with different sizes, ranging from 20 to 500 nodes per polygon, with 20 polygons generated for each size, are executed. The means are represented in the graph.

The results in Figure 9 show the performance of the Navmesh algorithm across normal, orthogonal, and isothetic polygons of varying sizes. Orthogonal polygons consistently demonstrate the fastest computation times, even as size increases. This is due to their simple geometry, which minimizes the need for complex subdivisions and enables efficient space partitioning. Since orthogonal polygons often represent real-world structures like grid-based buildings, these results highlight the practical applicability of Navmesh in such environments. Additionally, the tight error bars indicate consistent performance across trials, confirming the robustness of the algorithm for this polygon type.

In contrast, normal and isothetic polygons exhibit significantly longer computation times as size grows. Normal polygons, with their irregular shapes, require more subdivisions to ensure convexity, increasing processing time. Isothetic polygons, despite being theoretically regular, often introduce small, complex geometries as they scale, contributing to substantial variability. This variability is evident in their wider error bars, suggesting less predictable performance. These findings emphasize the computational challenges of irregular geometries and the importance of selecting appropriate polygon types for efficient Navmesh execution in real-world applications.

The next tests, shown in Figure 10 are about the order of the nodes. The original article does not talk about the order: we take the interest areas of the notches and we find for each notch its closest element, but we don't know in which order the notes are considered. For this test, we compute how many portals were added when considering the same polygon using different orders. We have considered five different orders:

- **Normal Order:** Notches are processed in a clockwise order around the polygon.
- **Random:** Notches are processed in a randomly determined order.
- **Biggest or Smallest Angles First:** Notches are ordered by their internal angle size, with the largest (or smallest) angles being processed first.

The results show that normal and random processing orders perform similarly, with no significant difference in the number of portals added. However, starting with the smallest angles increases portal count, especially for larger polygons, as small internal angles create complex subdivisions early. In contrast, prioritizing larger angles simplifies the problem earlier, reducing subdivisions. Regardless of order, portal count grows linearly with polygon size.

For random polygons, the results highlight promising real-world applications. Orthogonal polygons, common in real buildings, compute significantly faster. Additionally, processing the largest angles first reduces portal count and graph density, improving shortest-path search efficiency. These findings are encouraging for practical use cases.

5.2 Real Use Cases

As part of the investigation, a program was developed to apply the algorithm to real-world cases. By using a GeoJSON file representing a real building as input, the program executes the algorithm on the building and generates a graph, which is then provided to the user.

Definition 6 (GeoJSON File)**.** *A GeoJSON file is a digital document containing geographical information in the form of polygons, lines, or points. The data is represented in terms of latitude and longitude.*

The graphs generated for real-world scenarios are both natural and accurately reflect the underlying environment. Figure 11 illustrates an example of a real-world case processed by the program. The portals generated are not excessive, and the resulting path appears natural and intuitive. This outcome demonstrates the effectiveness of the algorithm in producing paths that closely mirror real-world navigation patterns, avoiding the creation of overly complex or unnatural routes while ensuring computational efficiency.

6 CONCLUSION

This paper shows that the Navmesh concept, widely used in video games, can be adapted to real-world environments. The proposed algorithm balances computational complexity and practical use, even with the NP-hard challenge of polygon division. While not always optimal, the results prove effective for real-life cases, especially with simpler structures.

Tests reveal the algorithm performs best on orthogonal polygons, typical of real-world buildings, thanks to their regularity, which simplifies the search space and reduces execution time. Irregular polygons, on the other hand, increase complexity as their size grows. Still, the algorithm remains scalable and efficient, even for larger inputs.

Node processing tests showed that prioritizing the largest angles reduces portal count, with all orders

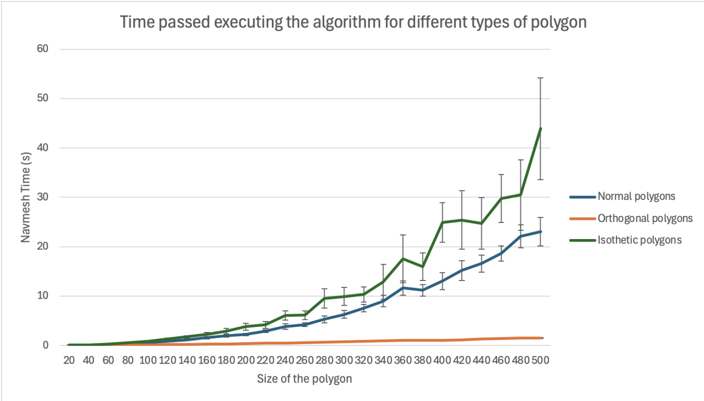


Figure 9: Time spent executing the Navmesh algorithm across different polygon types and sizes. The error bars represent the 95% confidence interval for the results. Isothetic polygons exhibit significantly greater variability while orthogonal polygons maintain consistently lower and more stable computation times, with barely visible confidence intervals.

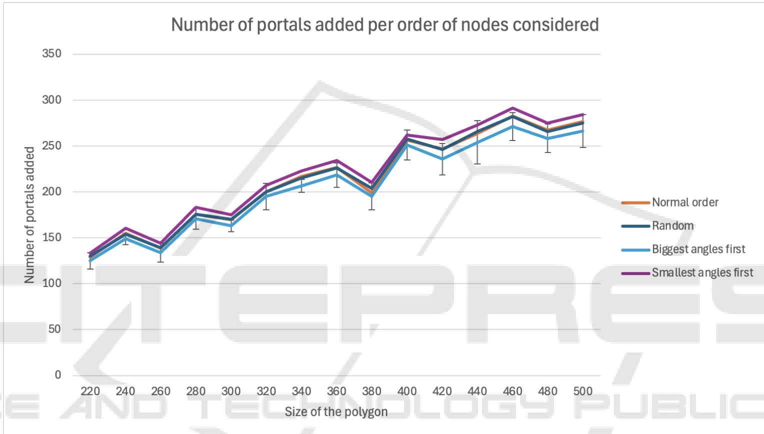


Figure 10: Number of portals added per node order considered. The confidence intervals for the biggest angles first strategy are shown: 95% of the values obtained in our simulations fall within 15% of the value represented on the plot. There are two middle bars, representing the normal and random values, which have very similar values.

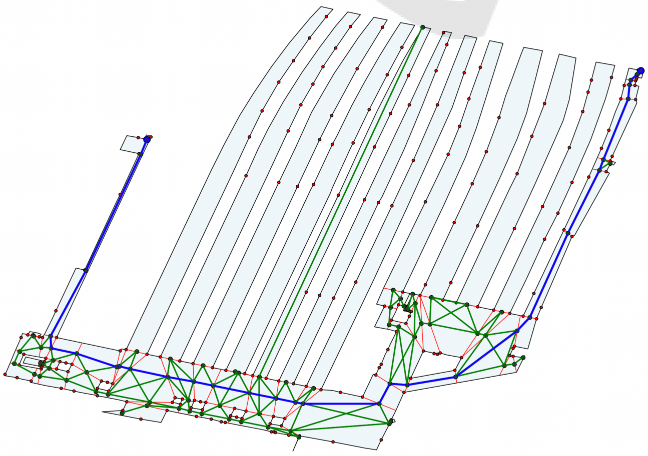


Figure 11: Application of the algorithm to a real use case. In red, the portals created by the algorithm, and in green the generated graph. In blue, a found shortest path crossing the station.

maintaining linear growth. Future work will focus on improving path "naturalness" and optimizing for realism over speed to ensure intuitive navigation solutions across various polygon types.

Future research will focus on applying this method to real-world scenarios and further investigating the "naturalness" of paths. Since the number of portals directly impacts the graph, future work could aim to optimize for path realism over speed, ensuring intuitive and context-appropriate navigation solutions across various polygon types.

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