

SeatGen - The Seating Plan Generation Tool For Stadiums

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Leonding, April 4, 2025

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Abstract

SeatGen is a tool developed for Solvistas GmbH to simplify stadium seating plan creation and management. It replaces the inefficient manual process with an intuitive graphical interface, allowing event organizers to design and edit seating layouts without technical expertise.

Built with React, Spring Boot & Kotlin, and Leaflet.js, SeatGen enables direct seat manipulation, real-time updates, and bulk modifications. This thesis explores the challenges, technologies, and implementation behind SeatGen.



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1 Introduction

1.1 Initial Situation

The company Solvistas GmbH is a software development company, and one of their main products is the Ticketing project. Ticketing is a software solution that enables customers to purchase tickets for seats or sections in stadiums and other venues hosting events. The software is used by various sports clubs and event organizers to manage ticket sales for their events.

1.2 Problem Statement

The as just mentioned stadiums and venues have a lot of seats and different areas, and therefore the Ticketing software needs to know the layout of the seats. These layouts can have lots of complex shapes like curves and other irregular shapes. The current process of creating these so-called seat plans is done manually by editing text files. There are many problems, and it's a very tedious process when editing seat plans within a text editor. To name a few: When changing the layout of a stadium, all the text files have to be reworked by a schooled developer. This costs the customer a lot of money, and the developer a lot of time. Also, it's very hard to imagine how the rendered plan looks, when staring at text files.

Uploading the plan image is another tedious task when creating new plans. To convert the given SVG file into a functional map compatible with their system, the developer must manually upscale and slice the SVG into tiles, repeating this process for each zoom level—typically 5 to 7 times. Additionally, since each tile is divided into four smaller tiles at every zoom level, the number of tiles increases exponentially. As a result, a massive number of files must be uploaded to an AWS S3 bucket, making the process even more time-consuming.

1.3 Goal

The goal of the diploma thesis was to develop a custom solution for the company Solvistas and solve all these aforementioned problems with a tool that's intuitive to use and easy to learn, saving time and costs. The goal was to create a visual editor that creates and manages seat plans for events in a stadium. This editor allows customers to create and edit new seating plans themselves, making the process so accessible and easy to use that no more schooled developers are required to make changes in a seating plan.

2 Context / Environment Analysis

3 Technologies

A complete visualization of the tech stack can be found in 1. Further details and explanations can be found in the following sections.

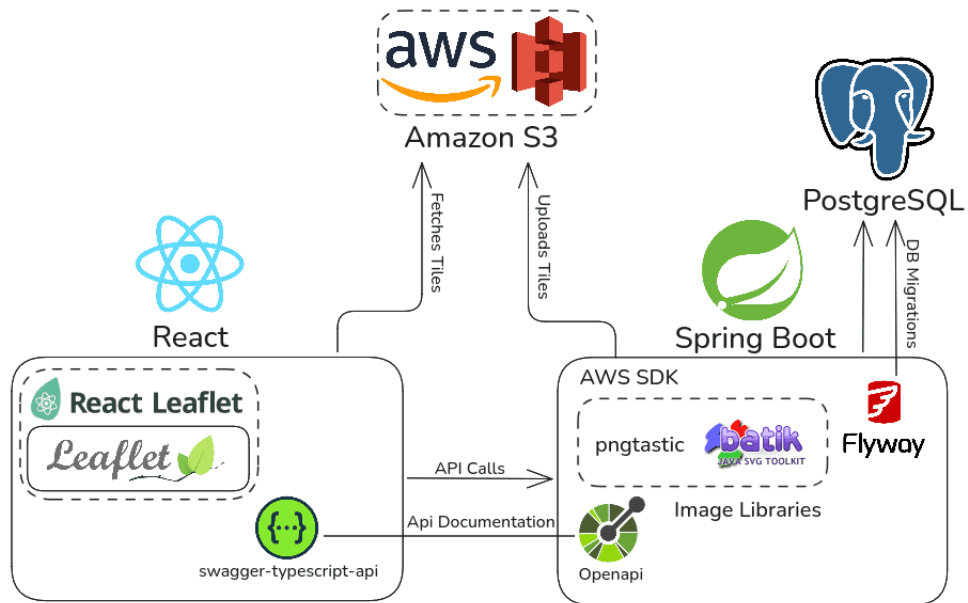


Figure 1: Tech Stack

3.1 React

3.2 Spring Boot and Kotlin

For the backend logic, Spring Boot was chosen as it is a core technology in Solvistas' tech stack. This decision ensures that the project remains maintainable by Solvistas developers in the long run. The backend has several key responsibilities, including:

- Handling the storage of the seatplan metadata
- Converting SVGs into image tiles
- Uploading the converted tiles to an S3 bucket
- Serving all of this data to the frontend via REST

For image processing tasks such as resizing and slicing SVGs and PNGs, Python was initially considered due to its well-documented and easy-to-use image manipulation

libraries like CairoSVG and OpenCV. However, the decision was ultimately made to keep the processing within the Java/Kotlin ecosystem, using libraries like Batik[1] and ImageIO[2]. While Java/Kotlin image processing is not as straightforward as Python due to less extensive documentation and fewer community resources, this choice allowed for a consistent backend technology stack. One challenge with Java-based image processing is memory management—heap size and garbage collection must always be considered, especially when processing large images. For file uploads, Amazon S3 provides excellent support for Java and Kotlin through the AWS SDK[3], accompanied by extensive documentation and examples. This integration made it easy to incorporate S3 into the backend for efficiently storing and retrieving image tiles.

3.2.1 Kotlin

As for the language, Kotlin was used in Spring Boot, even though it is not commonly employed in many of Solvistas' projects. However, Kotlin was deemed the better option because it is a modern language that is fully interoperable with Java and offers many features that facilitate writing clean and concise code, thereby reducing errors and improving readability and maintainability. It eliminates much of the boilerplate code required in Java and provides a rich standard library with numerous built-in utility functions, significantly reducing development time. While Kotlin does not offer essential functionalities that Java cannot provide, it is more modern and has a more concise syntax.

Additionally, Kotlin introduces powerful features such as null safety, which helps create more robust applications with fewer runtime errors. Furthermore, Kotlin provides strong support for functional programming, including higher-order functions, lambda expressions, and extension functions, making it easier to write expressive and reusable code. Another key advantage is Kotlin's coroutines, which enable highly efficient asynchronous programming without the complexity of Java's traditional thread management. This makes Kotlin particularly well-suited for handling concurrent tasks, such as processing multiple image transformations simultaneously, significantly reducing processing time.

Kotlin's seamless integration with Spring Boot also allows for idiomatic DSLs (Domain-Specific Languages), which can simplify configuration and reduce verbosity in code. The language's structured concurrency and intuitive syntax contribute to cleaner, more maintainable backend services, ensuring long-term scalability. Finally, Kotlin's growing

adoption within the Spring ecosystem, along with first-class support from JetBrains and the Spring team, makes it a viable choice for modern backend development. Its developer-friendly nature, combined with reduced verbosity and enhanced safety features, positions it as a forward-thinking investment despite its lower adoption within Solvistas' existing projects.

In the end, Spring Boot with Kotlin was chosen due to the team's expertise with the language and the fact that all other components of the Ticketing software were already written in Spring Boot.

3.2.2 API Documentation with Swagger

SeatGen also utilizes SwaggerUi and SwaggerUi codegen to generate REST API documentation and client code for the frontend. This allows for easy integration of the backend with the frontend and ensures that the frontend developers always have the most up-to-date API documentation. This is done via the OpenApi gradlew plugin, which generates the SwaggerUi documentation and client code for all the API endpoints and required models. The generated docs can be fetched by the frontend developers with a script within the `package.json` file, under the name `fetch-openapi-docs`. This script fetches the `api-docs.yaml` file from the backend and saves it in the frontend project. When starting or building the frontend, the `swagger-typescript-api` plugin generates the client code from this file. The frontend developer now can use the generated client code to interact with the backend API through the generated functions and models without having to manually maintain the API client code.

3.3 Database

PostgreSQL was chosen as the database for several key reasons. A relational database is required since the data follows a structured design that is best represented through classical relational models. The structure of the database is visualized in the class diagram 2. Additionally, utilizing a relational database simplifies the process of exporting generated data into the Ticketing database, which also adheres to a relational structure.

The system is designed to be compatible with multiple relational databases, not just PostgreSQL, as the Java Persistence API (JPA) is utilized as the Object-Relational

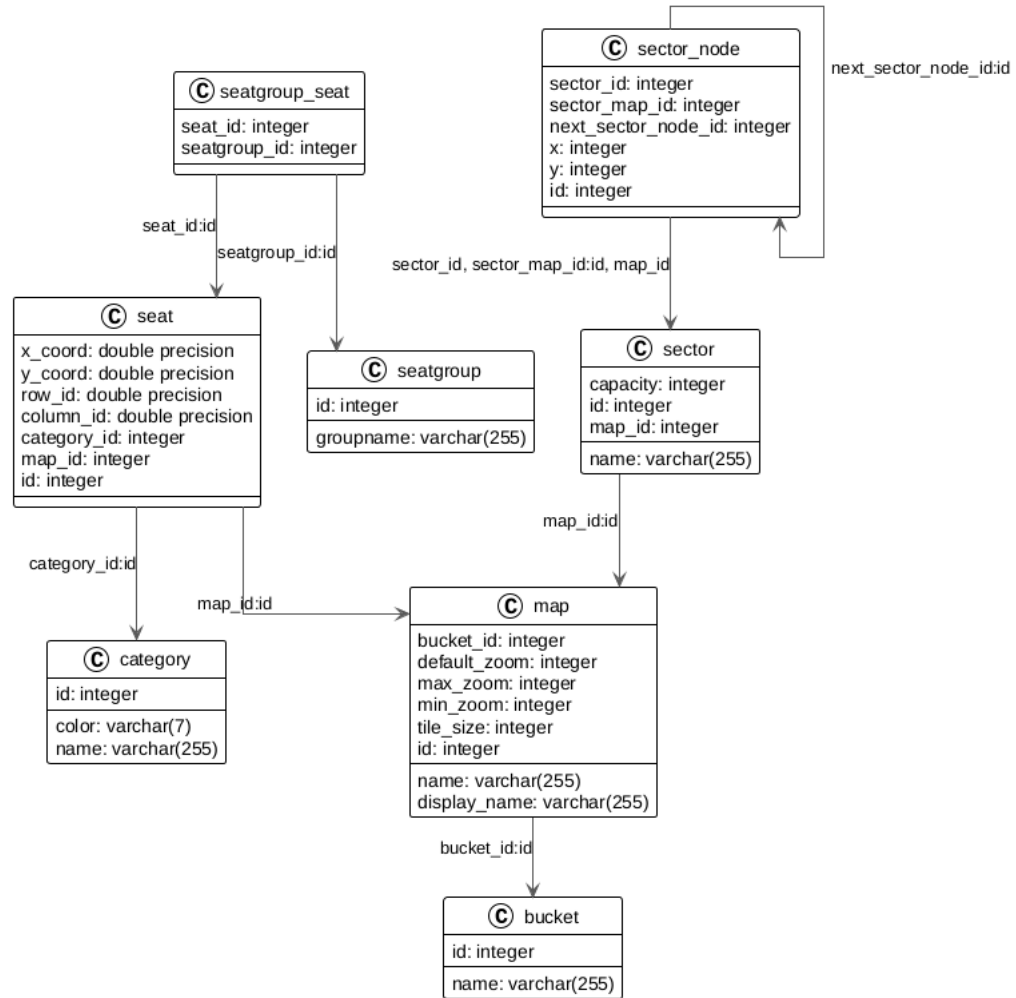


Figure 2: Database Model

Mapping (ORM) framework. To maintain database flexibility, PostgreSQL-specific commands were deliberately avoided. While leveraging PL/pgSQL for business logic could have provided benefits such as enhanced security, improved performance, and greater data consistency, database interchangeability was prioritized.

For database connectivity in the Spring Boot application, the Spring Data JPA library was utilized. This library streamlines the process of connecting to a database and executing queries while implementing the repository pattern. Through this pattern, custom queries are defined in an interface, which Spring Boot automatically implements at runtime. This approach simplifies query management, making it easier to maintain and use repository methods directly within the codebase.

To manage database migrations efficiently, the Flyway [4] library is used. Flyway enables the to define database changes through SQL scripts that execute automatically when the application starts. This ensures that the database schema remains consistent with the latest changes, simplifying deployment and mitigating potential conflicts across different environments. Managing migrations this way also helps prevent issues arising from different database versions among team members. Additionally, since Flyway migrations consist of entire SQL scripts, both Data Definition Language (DDL) and Data Manipulation Language (DML) commands can be executed. This capability is particularly beneficial for tasks such as migrating data between tables, altering column data types, and implementing other business logic-related transformations.

When selecting a migration tool, both Liquibase [5] and Flyway were evaluated. While both are open-source and provide seamless integration with Spring Boot and other Java frameworks, the decision was ultimately made to opt for Flyway due to its simplicity and specific use case. Since the team is small with infrequent parallel database changes, Flyway's linear migration approach suits the workflow without introducing complications. Although this approach might present challenges in larger teams with concurrent database modifications, it remains a practical choice for current needs.

Flyway also offers a cleaner versioning system by requiring migration filenames to follow a structured naming convention: `VX.X.X_migration_name.sql` (where X.X.X is the version of the migration). In contrast, Liquibase utilizes changelog files, which provide additional features but introduce unnecessary complexity for the use case. These changelog files can be written in SQL, XML, YAML, or JSON, but they require extensive Liquibase-specific formatting. The following example illustrates a Liquibase-formatted

SQL changelog file 1. Flyway’s approach, which relies on plain SQL migration files, enhances readability and maintainability.

Listing 1: Liquibase example changelog

```
1      --liquibase formatted sql
2
3      --changeset nvoxland:1
4      create table test1 (
5          id int primary key,
6          name varchar(255)
7      );
8      --rollback drop table test1;
9
10     --changeset nvoxland:2
11     insert into test1 (id, name) values (1, 'name 1');
12     insert into test1 (id, name) values (2, 'name 2');
13
14     --changeset nvoxland:3 dbms:oracle
15     create sequence seq_test;
```

To ensure database consistency, Flyway generates a `flyway_schema_history` table that tracks all executed migrations. This table stores metadata for each migration, including the version, description, execution timestamp, and a checksum. The checksum prevents modifications to previously applied migrations, ensuring consistency but potentially causing unexpected errors during local development. In such cases, manual intervention in the `flyway_schema_history` table may be required, but except for these rare cases the `flyway_schema_history` table should not be manipulated manually.

By maintaining this history, Flyway can determine which migrations have been applied and which are still pending. Each migration also has a state, which can be pending, applied, failed, undone, and more—detailed in the Flyway documentation. These states allow system administrators to quickly identify and resolve migration and deployment issues.

When considering how to store image data, PostgreSQL’s built-in options, including BLOBs (Binary Large Objects) and TOAST [6] (The Oversized-Attribute Storage Technique), were evaluated. While these mechanisms allow PostgreSQL to handle large binary files, the decision was ultimately made against using them due to performance concerns, maintenance overhead, scalability limitations, and company reasons. Even though, TOAST is very performant and automatically compresses and stores large column values outside the main table structure, making it a more attractive option than traditional BLOBs, accessing and manipulating the stored images via SQL queries can become a bottleneck. ORMs like Hibernate tend to retrieve large column values by default unless explicitly configured otherwise, potentially leading to performance degradation when dealing with frequent queries. This means extra effort would be

required to optimize database queries to avoid unnecessary data retrieval, increasing development complexity.

3.4 AWS - S3

For image processing tasks such as resizing and slicing SVGs and PNGs, Python was initially considered due to its well-documented and easy-to-use image manipulation libraries like CairoSVG and OpenCV. However, the decision was ultimately made to keep the processing within the Java/Kotlin ecosystem, utilizing libraries such as Batik and ImageIO. While image processing in Java/Kotlin is not as straightforward as in Python due to less extensive documentation and fewer community resources, maintaining consistency within the backend technology stack was prioritized. One challenge associated with Java-based image processing is memory management—heap size and garbage collection must always be considered, especially when processing large images. For file uploads, Amazon S3 provides excellent support for Java and Kotlin through the AWS SDK, with extensive documentation and examples. This facilitated seamless integration of S3 into the backend for efficient storage and retrieval of image tiles.

In the Ticketing project, all image tiles are stored in an AWS S3 bucket. S3 was required due to its robust performance, reliability, and seamless integration with the AWS ecosystem, which is already in use at Solvistas. By utilizing the Amazon S3 SDK, the file upload process is automated, reducing manual effort and minimizing the risk of errors.

Using S3 also improves frontend performance by ensuring that image retrieval does not depend on the backend server's speed. Instead of acting as a middleware for serving images, the backend delegates this task directly to S3, reducing its workload and enhancing response times.

AWS S3 was the only option considered, as it is the cloud platform used by Solvistas, and the infrastructure costs are funded by the company.

3.5 Leaflet

4 Implementation

4.1 Frontend Architecture

4.2 Leaflet Integration

To integrate Leaflet[7] in SeatGen the React Leaflet library[8] was utilized as a wrapper for Leaflet, because of the easier React implementation. The library provides a set of React components for Leaflet maps, instead of just having to use the javascript functions of the Leaflet library. To get started with the integration of a basic map the **MapContainer** component and a map reference. The **MapContainer** is the area in the frontend where the map is displayed. The map reference is used to interact with the map, like adding layers or markers. The following code snippet shows how to create a basic map with the React Leaflet library. To make a map appear, there needs to be a **TileLayer** as a child of the **MapContainer**. There can also be multiple **TileLayer** components, to display different map layers, but it's not needed in the usecase of SeatGen. The one required property of the **TileLayer** is the **url** property, which is the URL of the map tiles. In the **url** property the place where **x**, **y** and **z** are placed is defined by the **{x}**, **{y}** and **{z}** placeholders. The **z** is the zoom level, **x** and **y** are the coordinates of the tile. A key part of the integration is the use of a map reference (**mapRef**), which allows programmatic interaction with the map instance. This reference is created using React's **useRef** hook and is used to manipulate the map dynamically, such as adding layers, adjusting zoom levels, or panning to specific locations.

The integration of custom markers in the map, the **Marker** component is used. The **Marker** component is a child of the **MapContainer** and has a position property.

Lots of different components utilize positions to display them on the map. Leaflet has two kinds of positions, the **LatLng** and the **Point**. The **LatLng** is a geographical point with a latitude and longitude. The **Point** is a point with **x** and **y** coordinates in pixels. The **Point** is used to position elements on the map, like markers or popups.

Latitude and longitude are used for representation of Earth's surface. Latitude specifies the north-south position and ranges from -90° (South Pole) to $+90^\circ$ (North Pole). Longitude specifies the east-west position and ranges from -180° to $+180^\circ$. These coordinates are used in geographic coordinate systems, which are essential for positioning objects on a global scale, but not useful for the usecase of SeatGen. When not transforming the coordinates correctly and using a marker, it can happen, that when moving a marker in a straight line, it will move in a curved direction. This is because of the aforementioned logic of the surface of the Earth. To avoid this, the `LatLng` coordinates can be converted to `Point` coordinates by providing the map reference. An example of such a conversion in the code of Seatgen is in listing 2

Listing 2: Latitude Longitude and Point conversion

```
1 //Point to LatLng
2 const latLngPosition = map.layerPointToLatLng(new L.Point(x, y));
3
4 //LatLng to Point
5 const pointPosition: Point = map.latLngToLayerPoint(new L.LatLng(lat, lng));
```

Leaflet also provides a lot of features which can be used by some part for this editor. This ranges from fully usable features, that don't need a lot of reconfiguration to work for SeatGen's usecase, to features that need to be reworked or where only a small part of the feature is utilized, and the rest is rewritten. Some of the features that could be just used as they were, were:

- Zoom
- Movement in the map
- Tooltips of markers

SeatGen has a lot more of Leaflet's features implemented, but they are heavily modified. For example: The marker feature was utilized for displaying seats, but other than the base features everything else isn't provided by Leaflet, but it's implemented here instead.

4.2.1 Writing Extensions

For the bigger changes inside Leaflet itself, SeatGen uses extensions, to modify existing features or even overwrite them. Leaflet provides an easy way for developers to do such a thing like modifying leaflet functionalities. This can be done with the `extend` method that is provided by some Leaflet classes. When overwriting functions, knowledge of the functionality of the leaflet internal functions that want to be overwritten is required. It's

recommended to look into Leaflet’s source code and study the class before overwriting it. When doing so, it is possible to create new subclasses of the existing class and integrating these new modded subclasses into the map. An example of this in SeatGen is in listing 3

Listing 3: Modifying Leaflet Features

```

1  L.Map.Multiselect = L.Map.BoxZoom.extend({
2
3      _onMouseDown: function (e) {
4          //...
5          //Business logic for overwriting here
6          //...
7      },
8
9      _onMouseMove: function (e) {
10         //...
11         //Business logic for overwriting here
12         //...
13     },
14
15     _onMouseUp: function (e) {
16         //...
17         //Business logic for overwriting here
18         //...
19     },
20
21     _finish: function () {
22         //...
23         //Business logic for overwriting here
24         //...
25     },
26
27 })
28
29 L.Map.mergeOptions({boxPrinter: true});
30 L.Map.addInitHook('addHandler', 'boxPrinter', L.Map.Multiselect);
31
32 L.Map.mergeOptions({boxZoom: false});

```

In the provided Leaflet extension code, `mergeOptions` is used to introduce and modify configuration options for the `L.Map` class. This method allows developers to add custom options to existing Leaflet classes without modifying the core library. By merging options and using `addInitHook`, the new feature seamlessly integrates with Leaflet maps. The result is that whenever a map instance is created, new Feature replaces the default `BoxZoom` functionality if `boxPrinter` is enabled.

4.2.2 Event Handling

Leaflet provides an extensive event system that allows developers to listen for and handle various user interactions within the map. This event system is crucial for SeatGen, as it enables dynamic updates and interactions based on user actions. Events in Leaflet can be categorized into different types, such as mouse events, keyboard events, and map-specific events.

Commonly used events in SeatGen include:

- **click**: Triggered when a user clicks on the map or an element.
- **mousemove**: Fires whenever the mouse moves over the map, useful for hover effects.
- **drag**: Used to detect when a user drags an element like a marker.

Handling events in Leaflet is straightforward using `useMapEvents`. When using this hook and adding it to the Map, a lot of events can be caught and handled. An example for the usage of this hook with the `click` event is shown in listing 4.

Listing 4: Handling Events in Leaflet

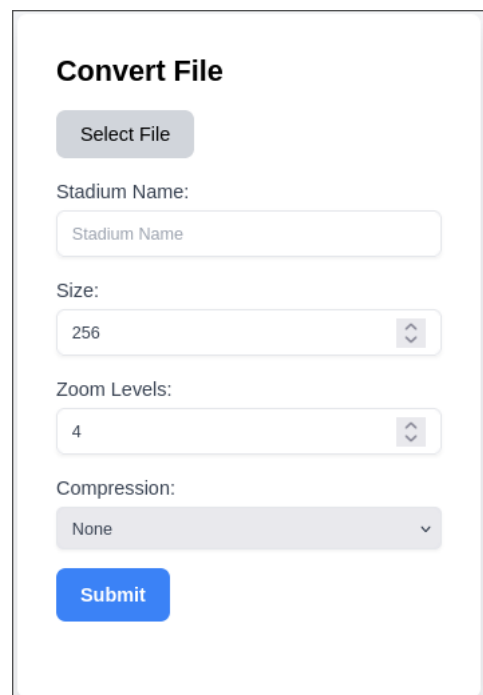
```

1  const MapEvents = () => {
2      useMapEvents({
3          click(e) {
4              console.log("clicked")
5
6              if (context.selectedToolId === "addTool" && mapClickCallBack) {
7                  console.log("Map clicked for add tool");
8                  mapClickCallBack(e);
9              }
10
11             if (context.selectedToolId === "default" || context.selectedToolId ===
12                 "") {
13                 context.setSeats(prevSeats => prevSeats.map(seat => ({ ...seat,
14                     selected: false })));
15                 context.setSelectedStandingAreaIds([]);
16             }
17         },
18     });
19     return null;
20 };
```

4.3 Map Generation

A significant milestone in the project was the development of the map generation functionality. This feature enables the user to generate an empty seat plan, which relies on the map to serve as the basic visual representation of the venue. The map is interactive in the frontend, and the user can configure several key parameters:

- The venue plan
- The name of the map
- The size of each tile (default is 256x256px for most use cases)
- The number of zoom levels



The screenshot shows a web form titled "Convert File". It contains the following elements:

- A "Select File" button.
- A "Stadium Name:" label followed by a text input field containing "Stadium Name".
- A "Size:" label followed by a numeric input field containing "256" and a small up/down arrow icon.
- A "Zoom Levels:" label followed by a numeric input field containing "4" and a small up/down arrow icon.
- A "Compression:" label followed by a dropdown menu showing "None" with a downward arrow.
- A blue "Submit" button at the bottom.

Figure 3: New Map Mask

- The image compression algorithm, which is a dropdown menu with the options: No Compression, Default Algorithm and Zopfli

These configuration options are accessible under the "New Map" button, as depicted in Figure 3.

The venue plan is always provided in SVG format, as the application does not support other file formats. To render the map, Leaflet, a JavaScript library designed for interactive maps, is used. A Leaflet map is structured as a 3-dimensional pyramid of tiles, where each tile represents an image. The map's zoom dimension can be considered the "z-axis," while the horizontal and vertical axes correspond to the "x" and "y" axes of the map. Importantly, the x and y axes remain consistent across all zoom levels.

As a result, each tile is defined by a 3-dimensional coordinate in the map. These tiles are retrieved from an S3 bucket and processed by Leaflet in the frontend. The map's structure follows the form of a 3-dimensional pyramid with a square base, progressively expanding as the zoom level increases. The number of tiles per zoom level grows exponentially by a factor of two.

For a given zoom level z , the number of tiles at that level is calculated as:

$$\text{Number of tiles}(z) = 4^{(z-1)}$$

The length of the side of the square base of the pyramid is:

$$\text{Length of side}(z) = 2^{(z-1)}$$

The total number of tiles is given by the sum:

$$S(z) = \sum_{k=1}^z 4^{(k-1)} = \frac{4^z - 1}{3}$$

As the number of zoom levels grows, the number of tiles that need to be processed rises exponentially, resulting in a significant increase in the total number of tiles very quickly. For example, there are already 4095 256x256px images with 6 zoom levels.

4.3.1 Step 1: Convert SVG to PNG

The first step in generating this map structure is to convert the SVG file into a PNG image. This process is handled by the backend using the Batik image transcoder. Apache Batik is a robust, pure-Java library developed by the Apache Software Foundation for rendering, generating, and manipulating Scalable Vector Graphics (SVG). Batik provides various tools for tasks such as:

- Rendering and dynamic modification of SVG files
- Transcoding SVG files into raster image formats (as done in this project)
- Transcoding Windows Metafiles to SVG

The size of the image is determined by the current zoom level. The width and height are calculated based on the logic described earlier and implemented in the Kotlin code snippet in Listing 5.

Listing 5: Image dimensions calculation

```
1 Dimension(frameSize * 2.0.pow(zoomLevel).toInt(), frameSize *  
    2.0.pow(zoomLevel).toInt())
```

If the image is not square, it is centered within a square canvas, with the remaining area filled with white. The resulting image is then converted to PNG format and written to a Java `ByteArrayOutputStream`, which is used in the subsequent processing step.

4.3.2 Step 2: Slicing the Image into Tiles

In this step, the PNG image generated in the previous step is sliced into smaller tiles. The size of the tiles is determined by the user, with 256x256px being the default. Given that the image is always square and its dimensions are divisible by the tile size, the image can be split into an integer number of tiles without complications.

The slicing process works by iterating through the image and extracting a sub-image of the specified tile size. This is done by calculating the appropriate coordinates for each tile and using the `Graphics.drawImage` method to copy the respective portion of the image into a new `BufferedImage` for each tile.

Here is the Kotlin code implementation for the slicing process:

Listing 6: Image Slicing Implementation

```
1 val subImage = BufferedImage(sliceSize, sliceSize, BufferedImage.TYPE_INT_ARGB)  
2 val graphics = subImage.createGraphics()
```

```
3  graphics.drawImage(image, 0, 0, sliceSize, sliceSize, x * sliceSize, y *  
    sliceSize, (x + 1) * sliceSize, (y + 1) * sliceSize, null)  
4  graphics.dispose()
```

In this code, `sliceSize` represents the size of each individual tile (e.g., 256x256px), and `x` and `y` are the coordinates of the current tile. The image is drawn on the `subImage` `BufferedImage`, which is a sub-region of the original image.

The resulting sub-images are saved as individual PNG files, each representing one tile of the map at the specified zoom level. These tiles are then uploaded to the S3 bucket so that the frontend can fetch them as needed. By splitting the image into tiles, it is possible to load and display the map interactively, only fetching the tiles that are currently in view. This tiling strategy is essential for efficient handling of large map layers at the later zoom levels.

LZ77 algorithm is a dictionary-based compression technique that replaces repeated occurrences of data with references to previous instances, reducing redundancy. Huffman coding, on the other hand, assigns shorter binary codes to more frequently occurring byte sequences, further optimizing storage efficiency. Together, these methods enable PNG files to achieve significant compression while maintaining full image fidelity.

4.3.3 Step 3: Compression

To optimize AWS costs and improve image loading speed in the frontend of the Ticketing project, images are compressed before being uploaded to the S3 bucket. However, this presents a challenge, as Solvistas requires PNG format for their project. Unlike lossy formats such as JPEG, which achieve smaller file sizes by discarding some image data, PNG is a lossless format, meaning it retains all original data. While this ensures sharp and clear images, it also results in larger file sizes, which can be problematic when numerous images are loaded from AWS in a web environment.

During the map generation process, users can choose from the following compression algorithms:

- **None** – No compression applied (fastest processing time, largest file size).
- **Default** – Standard compression using Deflate (balanced efficiency).
- **Zopfli** – Advanced, high-efficiency compression (better compression rates, slower processing).

The None option results in a 0% compression rate, making it the fastest but least efficient choice.

For the other two compression options, the Pngtastic library is utilized. Pngtastic is a lightweight, pure Java library with no dependencies. It provides a simple API for PNG manipulation, supporting both file size optimization and PNG image layering.

The Default option, uses the Deflate algorithm, which is used for as a base for many lossless compression algorithms, which combines LZ77 and Huffman coding.

- **LZ77** is a dictionary-based compression method that reduces redundancy by replacing repeated sequences of data with references to earlier occurrences, thus minimizing file size without loss of quality.
- **Huffman coding** optimizes storage efficiency by assigning shorter binary codes to frequently occurring byte sequences, further improving compression rates.

Together, these methods enable PNG files to achieve significant compression while maintaining full image fidelity.

The Zopfli algorithm[9], developed by Google engineers Lode Vandevenne and Jyrki Alakuijala in 2013, offers an advanced, high-efficiency compression technique. While it still utilizes the Deflate algorithm, it applies exhaustive entropy modeling and shortest path search techniques to achieve a higher compression ratio than standard Deflate and zlib[10] implementations. Zopfli achieves superior data compression by extensively analyzing different possible representations of the input data and selecting the most efficient encoding. By default, Zopfli performs 15 iterations to refine compression, though this can be adjusted for higher or lower processing times. Under standard settings, Zopfli output is typically 3–8% smaller than zlib’s maximum compression, but it is approximately 80 times slower due to its computational intensity.

According to Google developers: [11]

...we believe that Zopfli represents the state of the art in Deflate-compatible compression.

While Zopfli is significantly slower than standard Deflate or zlib, but this isn’t a huge problem for this usecase, because time can be sacrificed once for the optimization and speed improvement for the user.

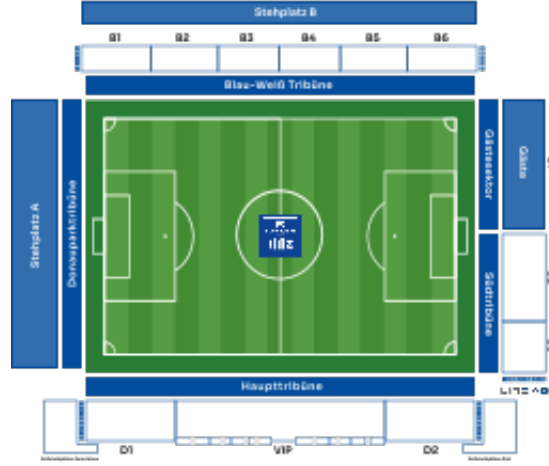


Figure 4: BW-Linz Stadium

Analysis of Compression Algorithms

By testing the compression algorithms within this application with different parameters, which range from the three algorithms, different maps, and different numbers of zoom levels, it can be observed that Zopfli is the best option for the compression of the images, provided that time is allocated for compressing the data. All the test results are visualized in the following table, and the image used for testing is the BW-Linz stadium 4, which is an example taken from production.

Zoom Level	Size Before Compression (Bytes)	Size After Compression (Bytes)	Time Taken (ms)	Percent Saved
0	12148	12148	98	0%
1	28218	28218	243	0%
2	61540	61540	652	0%
3	131470	131470	1424	0%
4	289606	289606	2815	0%
5	700382	700382	7275	0%

Table 1: Compression Results for NONE Compression Method

Zoom Level	Size Before Compression (Bytes)	Size After Compression (Bytes)	Time Taken (ms)	Percent Saved
0	12148	10043	533	17.47%
1	28218	24710	1477	12.43%
2	61540	58638	4534	4.99%
3	131470	131226	14397	0.19%
4	289606	289134	51388	0.16%
5	700382	699310	180054	0.15%

Table 2: Conversion Results for DEFAULT Compression Method

Zoom Level	Size Before Compression (Bytes)	Size After Compression (Bytes)	Time Taken (ms)	Percent Saved
0	12148	9745	13179	19.73%
1	28218	23343	35591	17.29%
2	61540	54519	111915	11.41%
3	131470	119405	363794	9.18%
4	289606	266976	1166758	7.82%
5	700382	658512	3004721	5.98%

Table 3: Conversion Results for ZOPFLI Compression Method

Compression Method	NONE	DEFAULT	ZOPFLI
Total Size Before Compression (Bytes)	1223364	1223364	1223364
Total Size After Compression (Bytes)	1223364	1213061	1132500
Total Bytes Saved (Bytes)	0	10303	90964
Total Percent Saved	0%	0.84%	7.44%
Total Time Taken (ms)	7519	195929	4696028
Total Time Taken (min)	0.13	3.27	78.27

Table 4: Summary of Conversion Results

To ensure that this test data is viable, the calculation has been computed with 4 dedicated processors, that were configured like this as java vm options:

```
-XX:ActiveProcessorCount=4
```

As observed in the summary table 4, Zopfli has amazing compression but is a very time-intensive process, as expected. In the end, it saves 6.6% more than the default

algorithm, but it takes approximately 24 times longer, and waiting times of over an hour should be anticipated when using the algorithm. This trade-off must be considered. Although this would only be a one-time process, the decision could favor Zopfli; however, in comparison to the total 90,964 bytes (88.83 KiB) saved, this is still not a significant amount of data saved when considering the time taken. Ultimately, all the data produced is not very large, so the operator must decide whether the time is worth the saved data. If the time and resources are not desired to be spent for such a low storage and performance improvement, the default algorithm remains a good choice, as a waiting period of 3 minutes and 16 seconds is still acceptable for a small optimization. As mentioned previously, it is crucial that the user can decide which algorithm should be used due to various factors. When the program is hosted on an external cloud provider with dynamic cost calculations, the user may not want to incur the extra costs associated with the Zopfli algorithm, as the expense for the additional time could exceed the savings from storage. If the program is executed locally or on servers with sufficient free resources, the Zopfli algorithm is an excellent choice.

Another significant decision during development was whether to compress the images before or after the slicing process. Ultimately, the decision was made to compress the images before slicing them into tiles. This approach was favored for several reasons.

Compressing the entire image as a whole is generally more efficient than compressing individual tiles. Compression algorithms benefit from analyzing the entire dataset, allowing them to identify and eliminate redundancies more effectively. When an image is compressed in its entirety, the algorithm can exploit correlations and patterns that might not be as apparent when processing smaller segments. This leads to a better overall compression ratio, resulting in reduced file sizes without sacrificing quality.

Had the choice been made to first slice the images and then compress the individual tiles in parallel, potential issues with resource contention would have arisen. In such a scenario, multiple instances of the Zopfli compression algorithm could run simultaneously, each consuming considerable CPU cycles and memory. Given Zopfli's high computational demands, this could overwhelm the heap space, leading to memory exhaustion or, at the very least, severely impacting overall system performance. In extreme cases, excessive resource usage could degrade the performance of the entire operating system, causing bottlenecks and slowdowns.

4.3.4 Step 4: Uploading Tiles to S3

The final step in the map generation process involves uploading the generated tiles to an Amazon S3 bucket. This is achieved using the AWS SDK for Java, which provides a robust and efficient way to interact with AWS services. The SDK allows us to create an S3 client, which facilitates seamless communication with the S3 bucket. The only required configuration parameters for the client are the AWS region (set to eu-central-1 in SeatGen’s case), the access key, and the secret key. Once configured, as demonstrated in Listing 7, the S3Client instance provides a range of operations, including putObject, getObject, and listObjectsV2, among others.

Listing 7: Configuring the S3 Client

```

1  @ConfigurationProperties(prefix = "aws")
2  data class S3Config @ConstructorBinding constructor(
3      val awsRegion: String,
4      val accessKey: String,
5      val secretKey: String
6  ){
7      @Bean(destroyMethod = "close")
8      fun s3Client() : S3Client {
9          return S3Client
10             .builder()
11             .overrideConfiguration(ClientOverrideConfiguration.builder()
12                 .apiCallTimeout(Duration.ofSeconds(10)).build()
13             )
14             .region(Region.regions()
15                 .find { region -> region.toString() == awsRegion }
16             )
17             .credentialsProvider(
18                 StaticCredentialsProvider.create(
19                     AwsBasicCredentials.create(accessKey, secretKey)
20                 )
21             )
22             .build()
23     }

```

The configuration is managed using the @ConfigurationProperties(prefix = “aws”) annotation, which enables automatic injection of required properties. These values—defined in the primary constructor with @ConstructorBinding—are retrieved from an external properties file under the aws prefix. This approach ensures that configuration values remain externalized rather than hardcoded, making it easier to switch between environments such as development, testing, and production. The relevant configuration in application.yml is illustrated in Listing 8.

Listing 8: AWS Configuration in application.yml

```

1  aws:
2      awsRegion: ${AWS_REGION:eu-central-1}
3      access-key: ${AWS_ACCESS_KEY}
4      secret-key: ${AWS_SECRET_KEY}

```

By using environment variables for sensitive credentials, security is enhanced while maintaining flexibility in deployment configurations. The SDK’s S3Client.builder() method is

used to instantiate and configure the client with the required credentials and region settings. Because the client is defined as a Spring bean, it can be easily injected into any class requiring interaction with the S3 bucket. This is a key advantage in Spring-based applications, as it promotes modularity and maintainability. Unlike in Quarkus, where dependency injection is handled differently, Spring allows defining such functions as beans and seamlessly injecting them where necessary.

The name provided by the user doesn't have any major restrictions for special characters, that's because the customer shouldn't be bothered with technical restrictions. They should be able to choose the name they want. Technically there are still some restrictions. The name provided by the user will be used in two situations, that have limitations.

1. Directory names in the S3 buckets
2. Path in the URL in the frontend for editor page

S3 looks like a standard file system, but actually it's not, and therefore the name for the "directory" doesn't have huge limitations.

Normally data in an Amazon S3 bucket, is stored in a flat structure instead of a hierarchy one as seen in standard file systems. Amazon still supports the organization of data like in file systems. This is done by giving all the grouped objects a shared string prefix. The prefix is therefore the folder name. The data, is actually still stored in a flat structure, but it's visualized like folders in the Amazon S3 console. [12]

The second place where the name is utilized is the URL path in the frontend. This is more restricted because it is part of the URL, and therefore some characters could lead to errors. The following characters are reserved and cannot be used in the URL path: `/&?=:%`. Using these characters leads to errors. For this reason, the name is prepared for the URL path by replacing these characters with an underscore. To still provide the user with the requested name, the original name is stored in the database alongside the prepared name. The original name is used solely for display purposes in the frontend.

Then the tiles are uploaded with the prefixes according to their coordinates. The final filenames are in the format `<mapName>/<z>/<x>/<y>.png`. The map name is the name provided by the user, and the zoom level, x, and y are the coordinates of the tile. The tiles are uploaded to the S3 bucket in a hierarchical structure, with each zoom level containing a set of directories for the x and y coordinates.

After executing all of these steps, they have to be repeated for each zoom level asked for.

4.3.5 Optimizations & Memory

This process involves repetitive and computationally demanding tasks such as image slicing, format conversion, and compression, making it well-suited for multi-threading. However, parallel execution introduces challenges, particularly with Java heap space management. During slicing and compression, a large amount of data is stored in memory at the same time. This includes both the upscaled source image and the processed image tiles, leading to high memory usage. At higher zoom levels, storage requirements can reach several gigabytes, potentially exceeding the allocated heap space and causing `OutOfMemoryError` exceptions.

To address this, the Java heap size can be manually adjusted using:

```
java -Xmx6g seatgen
```

This increases the maximum heap allocation to 6 GB, allowing for more memory-intensive operations. On 32-bit systems, the heap size should not exceed 2 GB, as Java will reject larger values and fail with an invalid memory allocation error.

While manually increasing the heap size is a possible solution, it was important to ensure that the application runs efficiently without requiring users to adjust memory settings, although this is recommended when planning to use the Zopfli algorithm. To achieve this, the number of parallel threads was limited to prevent excessive memory usage, and a cap was placed on the maximum zoom level. At higher zoom levels, the processing demands grow exponentially, making it impractical to handle them within a Java-based backend. If future requirements necessitate even higher zoom levels, a more efficient approach could involve using a language like C, Rust, or Python, which offer better memory management for such intensive operations. However, since the company currently does not require zoom levels beyond level 6, this remains an optimization for future development.

To further optimize performance and manage concurrency effectively, Kotlin coroutines were utilized. Coroutines provide a lightweight and efficient way to handle asynchronous programming, allowing tasks like image slicing, compression, and uploading to be performed in a non-blocking manner. Unlike traditional threads, coroutines are more

memory-efficient and can be launched in large numbers without overwhelming the system.

For example, during the slicing and compression phases, coroutines were used to parallelize tasks such as processing individual rows of tiles. This approach maximized CPU utilization while keeping memory usage under control. By structuring the workflow with coroutines, it was possible to ensure that tasks like garbage collection and memory cleanup could be triggered at appropriate intervals, preventing memory leaks and excessive heap usage.

The limitation logic for the number of threads for parallelization is based on the algorithm used for compression, because for Zopfli, this is the most memory-critical part. When using Zopfli, which is particularly memory-intensive, parallelism is limited to a single thread during the compression phase. This approach ensures that the system's memory is not overwhelmed, allowing for more efficient processing. However, the slicing of image rows can still be executed with a maximum of four coroutines running concurrently, striking a balance between performance and resource usage. For the DEFAULT compression algorithm, a more aggressive approach is adopted, utilizing half of the available threads. This strikes a balance between efficient processing and maintaining manageable memory consumption. In scenarios where no compression methods are applied, the full use of the available processor threads is permitted. By limiting the number of concurrent coroutines when using Zopfli or the default algorithm, the risk of exceeding heap space during high-demand processes like compression and slicing is mitigated.

After each complete calculated zoom level, a garbage collection is triggered to free up memory that is no longer needed. This is done by calling the `System.gc()` method, which is a hint to the JVM to run the garbage collector. While this is not a guarantee that the garbage collector will run, it provides a good hint for the JVM to do so.

Because of memory problems, it was also decided not to upload all the data of the images when everything is finished. Instead, the data for each row of tiles is uploaded as soon as it is completed. This approach provides a good balance between memory usage and efficiency, as storing all the data in memory while waiting for other rows to be computed is avoided. Uploading the tiles in the form of rows is also more efficient than uploading every tile individually to the S3 bucket, as it significantly reduces the overhead. For example, on zoom level 6, only 63 requests need to be made instead of 1365 requests.

4.4 AWS - S3

As already mentioned in the technology section, integrating AWS services into the project required a reliable way to interact with AWS APIs. The AWS SDK provides language-specific libraries that simplify communication with AWS services, including S3.

For administrators and developers, AWS provides multiple ways to interact with its services, each suited for different use cases:

- **AWS Management Console (Web UI)** – A user-friendly graphical interface for managing AWS services, ideal for beginners or when making quick changes.
- **AWS Command Line Interface (CLI)** – A powerful command-line tool that allows users to manage AWS resources via scripts and commands, enabling automation and repeatability.
- **AWS SDKs – Language-specific libraries** (such as those for Python, Java, and JavaScript) that facilitate programmatic interaction with AWS services, making integration into applications seamless.
- Others can be found in the AWS documentation.

For configuring the S3 Pod, the AWS CLI tool was utilized instead of the AWS Management Console due to its greater efficiency and the ability to save previously used queries in a text format. While the CLI is less beginner-friendly than the Web UI, it offers significantly more powerful functionalities. When configuring an S3 Pod with the AWS CLI tool for the first time, thoroughly reviewing AWS documentation is recommended to understand the underlying concepts, as numerous configuration options impact the security of the application. Cost considerations were not a concern in this project, as the IAM user provided by the company lacked permissions to modify billing-related settings. However, certain cost factors remain dependent on the development process rather than the configuration of the bucket itself.

To set up the CLI tool, the for the developers operating system appropriate installation method has to be chosen. The specifics are well documented on the AWS's documentation page. For the initial configuration of the CLI tool, the command `aws configure` has to be executed. This command will prompt the user to enter the access key, secret key, region, and output format. The access key and secret key can be obtained from the AWS Management Console. The region is the geographical location where the S3 bucket will be created, in this case it is `eu-central-1`, and the output format can

be set to JSON, text, or table. The configuration is stored in two files located under linux in `~/.aws/` directory. In this directory lie the `config` and `credentials` files. The `config` file contains the region and the output format, while the `credentials` file contains the access key and the secret key. The configuration can be changed at any time by executing the `aws configure` command again. These files can contain multiple profiles, for multiple developers. This is very useful when working in a team, or when working on multiple projects. The profile can be specified by adding the `--profile` flag to the `aws` command.

Other than for testing and managing bucket configuration, the AWS CLI was a very useful tool during development, because it allows the developer to manipulate the data in the buckets manually, as well as reading and listing the data with additional statistics.

Some of the useful utility commands used during the development process are listed in listing 9

Listing 9: Usefull AWS CLI Commands

```

1  # Lists all buckets
2  aws s3 ls --profile myprofile
3
4  # Command to recursively delete every item inside a directory
5  aws s3 rm --profile --recursive s3://ticketing-stadium-creator-dev/my-bucket/
6
7  # List all the data inside directory and provide statistics, like file size,
   object count and tota filesize
8  s3 ls --profile solvistas --summarize --human-readable --recursive
   s3://ticketing-stadium-creator-dev/my-bucket
9
10 # Count the number of objects in a bucket (similar but more compact results than
   in the previous command)
11 aws s3 ls --profile solvistas --recursive s3://ticketing-stadium-creator-dev/ | wc
   -l
12
13 # Listing all the applied bucket policies
14 aws s3api get-bucket-policy --profile solvistas --bucket
   ticketing-stadium-creator-dev

```

4.4.1 S3 Bucket Configuration

The configuration of an S3 bucket is a crucial step in setting up an S3 pod, as it determines access permissions, storage classes, and other settings that influence the bucket's behavior. Several key configuration options were implemented in this project:

To enable access to the S3 bucket for all users, the `aws s3api put-bucket-policy` command was utilized. This command applies a bucket policy that defines specific permissions for the bucket. In this case, public read access to the objects in the bucket was required.

The following command was executed: 10 with the `bucket-policy.json` configuration 11.

Listing 10: AWS CLI command to set a bucket policy

```
1 aws s3api put-bucket-policy --bucket ticketing-stadium-creator-dev --policy
  file://bucket-policy.json
```

Listing 11: Bucket policy JSON configuration

```
1 {
2     "Version": "2012-10-17",
3     "Statement": [
4         {
5             "Effect": "Allow",
6             "Principal": "*",
7             "Action": "s3:GetObject",
8             "Resource": "arn:aws:s3:::ticketing-stadium-creator-dev/*"
9         }
10    ]
11 }
```

This policy allows any user (`Principal: "*"`) to perform the `s3:GetObject` action on all objects (`Resource: "arn:aws:s3:::ticketing-stadium-creator-dev/*"`) within the bucket.

Amazon S3 provides **Access Control Lists (ACLs)** to manage access to buckets and objects. ACLs are a legacy access control mechanism, but they are still useful for simple use cases. Here are some important ACLs:

- **Private:** The bucket and objects are accessible only by the bucket owner. This is the default ACL for new buckets.
- **Public Read:** The bucket and objects are readable by anyone on the internet. This is useful for hosting static websites or publicly accessible files.
- **Public Read-Write:** The bucket and objects are readable and writable by anyone on the internet. This is generally not recommended due to security risks.
- **Authenticated Read:** The bucket and objects are readable by any authenticated AWS user (not just the bucket owner).

While ACLs are easy to use, they are less flexible than bucket policies or IAM policies. For more granular control, it is recommended to use bucket policies or IAM policies. IAM (Identity and Access Management) policies provide fine-grained access control to AWS resources. Unlike bucket policies, which are attached to the bucket, IAM policies are attached to IAM users, groups, or roles. For this use case bucket policies were sufficient, because the bucket was only used to store static files, which should be accessible by everyone.

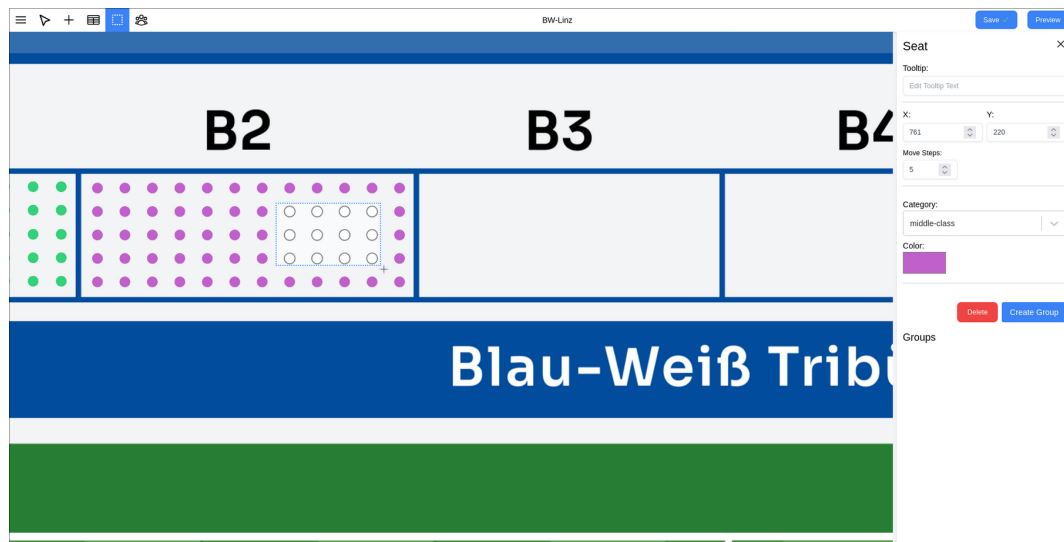


Figure 5: Multiselect Tool

4.5 Add-Tool

4.6 Multiselect-Tool

A very important feature was enabling the user to select multiple seats at once. This was especially crucial because a venue can have many seats, and selecting them one by one would be very time-consuming. A common operation for the user is also moving entire sectors. To tackle this challenge, the decision was made to develop the multiselect tool. The multiselect tool draws a rectangle when selected and dragged on the map, selecting everything inside this rectangle. For the rectangle part, Leaflet already provides a feature that uses a rectangle, which works on the user's drag interaction. This feature is called BoxZoom. The BoxZoom feature is a built-in capability of Leaflet that allows the user to draw a rectangle on the map and zoom into the area of the rectangle. This feature served as a good starting point for the multiselect tool because it already provides rectangle drawing and drag interaction. The BoxZoom feature was extended to develop the multiselect tool. The multiselect tool is a subclass of the BoxZoom feature and overrides the functions responsible for zooming. Instead of zooming, the multiselect tool selects all the seats inside the rectangle. The multiselect tool is shown in listing 12. The finished functionality for selecting seats is shown in figure 5.

Listing 12: Multiselect Tool

```

1  const MapBoxSelect = (props) => {
2    const propsRef = useRef(props);
3
4    useEffect(() => {
5      propsRef.current = props;
6    }, [props]);
7  }

```

```

8     let _startPoint;
9     let _currFunction;
10
11     function checkIfNothingSelected() {
12         const currentProps = propsRef.current;
13         return (currentProps.currentSelectedTool === undefined ||
14             currentProps.currentSelectedTool === null ||
15             !(currentProps.currentSelectedTool.id in currentProps.handleDrag));
16     }
17
18     L.Map.Multiselect = L.Map.BoxZoom.extend({
19         _onMouseDown: function (e) {
20             if (checkIfNothingSelected()) {
21                 return false;
22             }
23             _currFunction =
24                 propsRef.current.handleDrag[propsRef.current.currentSelectedTool.id]
25                 L.DomUtil.disableTextSelection();
26                 propsRef.current.mapRef.current?.dragging.disable()
27
28             _startPoint = this._map.mouseEventToLayerPoint(e);
29
30             this._box = L.DomUtil.create('div', 'leaflet-zoom-box', this._pane);
31             L.DomUtil.setPosition(this._box, this._startLayerPoint);
32
33             this._container.style.cursor = propsRef.current.currentSelectedTool;
34
35             L.DomEvent
36                 .on(document, 'mousemove', this._onMouseMove, this)
37                 .on(document, 'mouseup', this._onMouseUp, this)
38                 .on(document, 'keydown', this._onKeyDown, this)
39                 .preventDefault(e);
40
41             this._map.fire('boxzoomstart');
42         },
43
44         _onMouseMove: function (e) {
45             if (checkIfNothingSelected()) {
46                 return false;
47             }
48             var startPoint = _startPoint,
49                 box = this._box,
50
51                 layerPoint = this._map.mouseEventToLayerPoint(e),
52                 offset = layerPoint.subtract(startPoint),
53
54                 newPos = new L.Point(
55                     Math.min(layerPoint.x, startPoint.x),
56                     Math.min(layerPoint.y, startPoint.y));
57
58             L.DomUtil.setPosition(box, newPos);
59
60             box.style.width = (Math.max(0, Math.abs(offset.x) - 4)) + 'px';
61             box.style.height = (Math.max(0, Math.abs(offset.y) - 4)) + 'px';
62         },
63
64         _onMouseUp: function (e) {
65             if (checkIfNothingSelected()) {
66                 return false;
67             }
68
69             this._finish();
70             const map = this._map,
71                 layerPoint = map.mouseEventToLayerPoint(e);
72             const bounds = new L.LatLngBounds(
73                 map.layerPointToLatLng(layerPoint),
74                 map.layerPointToLatLng(_startPoint)
75             )
76
77             if (_currFunction !== null) {
78                 _currFunction(bounds);
79             }
80             _currFunction = null
81         },
82
83         _finish: function () {
84             propsRef.current.mapRef.current?.dragging.enable()
85             if (Array.from(this._pane.children).includes(this._box)) {
86                 this._pane.removeChild(this._box);
87             }
88             this._container.style.cursor = '';
89         }
90     });

```

```

87         L.DomUtil.enableTextSelection();
88
89         L.DomEvent
90             .off(document, 'mousemove', this._onMouseMove)
91             .off(document, 'mouseup', this._onMouseUp)
92             .off(document, 'keydown', this._onKeyDown);
93     },
94
95     })
96
97     L.Map.mergeOptions({boxPrinter: true});
98     L.Map.addInitHook('addHandler', 'boxPrinter', L.Map.Multiselect);
99
100    L.Map.mergeOptions({boxZoom: false});
101 }
102
103 export default MapBoxSelect

```

This code uses parts of the original code concepts, and adapts it for the selecting of seats. The original source can be found in Leaflet's source code.

This box is utilized not only for the multi select tool, but also for the grid tool which is explained in more detail in section 4.7. The modification of the ZoomBox only need to be done once, because they can be reused by both tools. The modified functionality just disables the zoom of the original feature, and accepts a function that is called onMouseUp with the boundaries of the drawn rectangle as parameters. When the rectangle select is needed it can be dynamically loaded into the map component.

Except for this tool another way of selecting multiple seats at once was implemented, because of usability reasons, and the expectancy of the user. In editors ranging from Photoshop, Gimp, to File Explorers, the holding of the `strg` or `cmd` key while clicking on an object, allows the user to select multiple objects. This was also implemented in SeatGen. The user can hold this key and click on a seat, to select more than one seat.

4.7 Grid-Tool

4.8 Standing-Area-Tool

4.8.1 Frontend

4.8.2 Backend

Because a standing area is in the for of nodes, which are connected to each other it can be viewed as a circular linked list. These have to be saved in the database. The database model is shown in figure 6. All the other tables are left out for simplicity's sake.

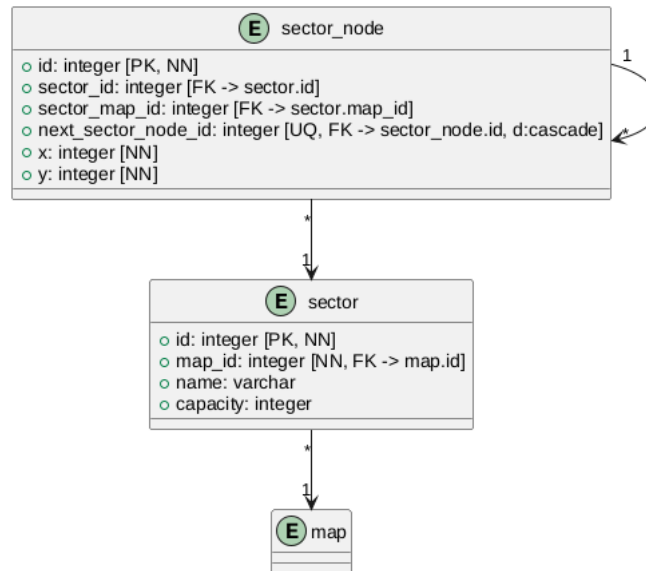


Figure 6: Standing Area Database Model

The `sector_node` entity in the database has a foreign key, that references itself. This allows us to model a hierarchy, and in this case this hierarchy looks like a loop. To ensure database integrity, a unique constraint is set on the `next_sector_node_id`. This makes sure, that there is only one sector node, that is the successor of a given sector node. When fetching a standing area two options were considered to do so.

1. Fetch all sector nodes from a map and build the standing area in the backend.
2. Make a recursive query in the database, that fetches all sector nodes of a standing area.

The advantage of the second approach is, that only the needed nodes are fetched, and the logic is closer to the db. The big problem is, that SQL queries in Postgres don't have a built-in way to do recursion like oracle db has with its `connect by` clause. The solution for Postgres would have to be implemented with PostgreSQL specific keywords. A query that fetches all the items in a loop would look as seen in listing 13.

Listing 13: Recursive Query

```

1  WITH RECURSIVE cte AS (
2      -- select first node with level 1
3      SELECT , 1 AS level
4      FROM    sector_node
5      WHERE   (select id from sector_node where map_id = 1 and sector_id = 1 LIMIT 1)
6              = id
7
8      UNION ALL
9      SELECT  sn., c.level + 1 as level
10     FROM    cte c
11             JOIN sector_node sn ON c.next_sector_node_id = sn.id where (select id
12                                     from sector_node where map_id = 1 and sector_id = 1 LIMIT 1) != sn.id
13 )
14 SELECT id, x, y
15 FROM    cte
16 ORDER BY level;
```

Here the `WITH RECURSIVE` clause is used to define a recursive query. The query selects the first node and then iterates through the linked list by repeatedly joining the `sector_node` table with itself using the `next_sector_node_id` field. This process continues until all nodes in the loop have been retrieved. The big disadvantage of this approach is, that it uses a PostgreSQL specific keyword, this makes it not possible to After executing all of these steps, they have to be repeated for each zoom level asked seamlessly switch to another database. This is why the first approach was chosen. The standing areas of the map are fetched in the backend and ordered recursively in a way, that represents the loop, like in listing 14.

Listing 14: Standing Area Backend

```

1  override fun getSectorNodeBySector(sector: Sector): Set<SectorNode> {
2      val startNode = db.getFirstSectorNodeBySector(sector.id!!)
3      return startNode.collectSectorNodes(startNode)
4  }
5
6  private fun SectorNode.collectSectorNodes(startNode: SectorNode): Set<SectorNode> {
7      return setOf(this) + (
8          if (next == startNode) emptySet()
9          else next?.collectSectorNodes(startNode) ?: emptySet()
10     )
11 }

```

4.9 Saving

SeatGen uses a save button to save the currently edited state and changes in the map. This has some advantages and disadvantages, against saving every time an action occurs. Some advantages are:

Advantages:

- The user can undo changes without saving them
- The user can save the changes when they are done, and try out stuff without instantly saving it, and overwriting the last state
- There is less load on the server, because multiple changes are saved at once
- A lot of load is avoided when doing a lot of small changes with lots of objects
- Only the important changes are saved, and not every step in between

Disadvantages:

- If the user forgets to save, all changes are lost
- There is an extra step the user has to execute

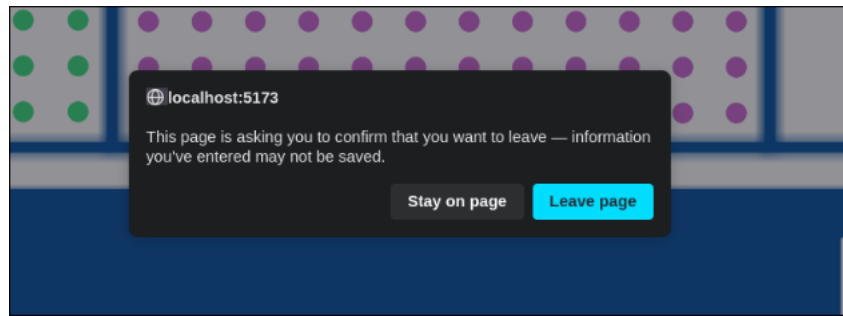


Figure 7: Leave Confirmation Dialog

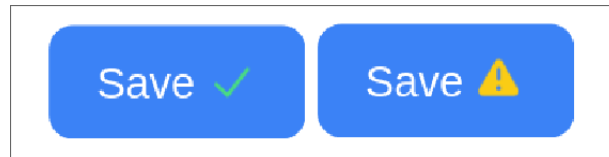


Figure 8: Save Button States

To mitigate these disadvantages, SeatGen uses a some techniques, like when the user is trying to leave the page via, reloading or closing the tab, the browser will ask the user if they are sure they want to leave the page, because there are unsaved changes. This is done by using the `beforeunload` event, which is triggered when the user tries to leave the page. This event is used to show a confirmation dialog to the user, which asks if they are sure they want to leave the page 7.

To ensure that the user doesn't forget to save, the save button is always visible, and always when the user has made changes, the save button is highlighted 8. This is done by the controller that manages the undo and redo functionality that is explained in section 4.10.1. The code 15 checks if there have been any actions by the user that are not the currently saved index, or if there are any standing areas that have to be saved or deleted. The standing areas have been managed differently for technical reasons.

Listing 15: Check for Unsaved Changes

```

1  function checkForUnsavedChanges() {
2      setHasUnsavedChanges(
3          historyIndex !== savedIndex ||
4          standingAreasToSave.length !== 0 ||
5          standingAreasToDelete.length !== 0
6      )
7  }
```

When saving the changes, first a checksum that is the hash of all seats and their properties is calculated and compared to the checksum of the initial loading of the map. If the checksums are the same, no seats will be saved, because they didn't change. If the checksum is different, a snapshot of the current seats is sent to the backend, for saving. For the standing areas there are two variables. `standingAreasToSave` and

`standingAreasToDelete`. These are set relative to the last saved state. When saving, the `toSave` get saved in the backend, and the `to delete` get deleted. After the save is successive both variables are empty. When creating a new standing area or deleting an existing one the variables get filled with the respective standing area. A big advantage over saving every time an action occurs is, that when creating and deleting an area without saving in between, there are no unsaved changes, and no traffic has to be sent instead of saving sending a request on its creation and deletion.

4.10 Design-Patterns

During the development of the application, various design patterns were incorporated to efficiently address specific challenges. Different sectors of the application required distinct patterns, particularly in the interactive editor and tool functionalities. Given the complexity of these components, tailored solutions were necessary. For instance, implementing an undo functionality—a widely expected usability feature in modern editors, both text-based and visual—required careful design considerations. This feature is commonly applied across software products, with multiple solutions available. Specialized implementations of design patterns were employed in the following aspects of the application:

- Undo/Redo functionality of Actions
- Tool System
- Backend services

4.10.1 Undo/Redo

The undo/redo mechanism is essential for usability, providing users with the flexibility to revert and reapply actions efficiently. Multiple approaches exist for implementing this feature:

1. **State Snapshot Approach:** This method involves saving the entire application state at each change and reverting to the previous state when undoing. While simple to implement, this approach is inefficient due to excessive memory consumption and redundant data storage. An advantage is, that old states can easily be restored without any additional logic and calculations. This makes it not very prone to bugs and errors.

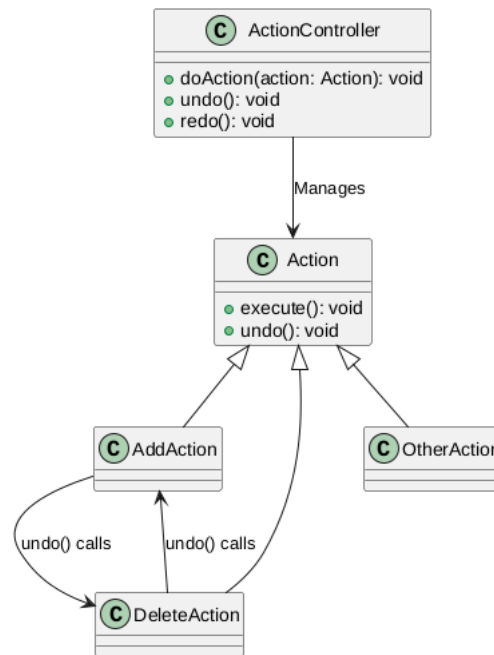


Figure 9: Command Pattern in SeatGen

2. **Differential State Storage:** Instead of storing complete states, this approach records only the differences between successive states, similar to version control systems such as Git. While more efficient, this method becomes complex as the number and types of objects increase (in this case it would be Seats and Standing-Areas).
3. **Command Pattern:** Actions are encapsulated as objects that implement a common interface, containing methods for execution and reversal. This approach allows flexible and scalable undo/redo functionality, making it ideal for complex interactive applications. It also allows to execute additional business logic when undoing an action, like deleting additional data that was created by the action, or sending requests to a backend. This makes it an excellent choice when the states are distributed.
4. **Memento Pattern:** This pattern captures and externalizes an object's internal state so that it can be restored later without violating encapsulation. While useful for preserving an object's complete state, it can be memory-intensive when storing multiple versions.

Given the application's complexity, a variation of the Command Pattern has been implemented for the undo/redo functionality. This approach ensures scalability, efficiency, and maintainability while minimizing redundancy of data and code.

The implementation defines an abstract `Action` class that all actions must implement. An overview of this is seen in 9. This class enforces the inclusion of `execute` and `undo` methods, ensuring a standardized approach to action management.

Listing 16: Action class

```
1 export abstract class Action {
2   execute: (() => void) | undefined;
3   undo: (() => void) | undefined;
4 }
```

For both of these properties a function is expected that can be called to execute the action or to `undo` the action. This is flexible approach and can be used for a lot of different actions.

Another importance for this application was to allow the execution of business logic while undoing specific actions, like sending requests to the backend. This is very easy to impliment because each Action has its individual `execute` and `undo` function.

While this seems like a lot more logic is needed than in the other design patterns, the logic demanded by this is actually important for usability reasons, and lots of it is reusable. Because the undo function should be able to be executed manually by the user, calling the `undo()` shouldn't be the only way to reverse an action, for example when creating a new seat, you should be able to delete it again by calling the `undo()` function as well as a separate way like a delete button. So the developer should always provide both ways for usability reasons. This approach incentivizes developers to do it because it's mandatory to implement the logic for undoing and action anyway.

Here is an implementation of an action that creates a Standing-Area with its counterpart action that deletes the standing area. Both actions can reference each other for the undoing part to reduce code redundancy, because the opposite of creating a standing area is deleting it. That's why deleting it is the undo action of creating it and the other way around.

Listing 17: Add standing-area action implementation

```
1 export class AddStandingAreaAction implements Action {
2   private readonly _newArea: StandingArea;
3   private readonly _context: MapContextValue;
4
5   constructor(newArea: StandingArea, context: MapContextValue) {
6     this._newArea = newArea;
7     this._context = context;
8   }
9
10  execute = () => {
11    this._context.setStandingAreas((prevAreas) =>
12      [...prevAreas, this._newArea]
13    );
14    if (this._context.standingAreasToDelete.includes(this._newArea.id))
15      {
```

```

16         this._context.setStandingAreasToDelete((prev) =>
17             prev.filter(id => id !== this._newArea.id)
18         );
19     } else {
20         this._context.setStandingAreasToSave((prev) => {
21             const updated = [...prev, this._newArea.id];
22             return updated;
23         });
24     }
25 };
26
27 undo = () => {
28     new DeleteStandingAreaAction([this._newArea], this._context).execute()
29 };
30 }

```

Listing 18: Delete standing-area action implementation

```

1  export class DeleteStandingAreaAction implements Action {
2      private readonly _deletedAreas: StandingArea[];
3      private _undoAreas: StandingArea[] | undefined;
4      private readonly _context: MapContextValue;
5
6      constructor(deletedAreas: StandingArea[], context: MapContextValue) {
7          this._deletedAreas = deletedAreas;
8          this._context = context;
9      }
10
11     execute = () => {
12         const deletedAreaIds = this._deletedAreas.map(area => area.id);
13         this._context.setStandingAreas((prevAreas) =>
14             prevAreas.filter((area) => !deletedAreaIds.includes(area.id))
15         );
16         this._context.setStandingAreasToDelete((prev) =>
17             [...prev, ...deletedAreaIds]
18         );
19         deletedAreaIds.forEach(id => {
20             if (this._context.standingAreasToSave.includes(id)) {
21                 {
22                     this._context.setStandingAreasToSave(this._context
23                         .standingAreasToSave
24                         .filter(savedId => savedId !== id));
25                 } else
26                 {
27                     this._context.setStandingAreasToDelete((prev) => [...prev, id]);
28                 }
29             });
30         }
31
32         undo = () => {
33             if (this._undoAreas) {
34                 this._deletedAreas.forEach((area) => {
35                     new AddStandingAreaAction(area, this._context).execute()
36                 })
37             }
38         }
39     }

```

In the code in Listing 17 and 18 you have the functions with the business logic for creating and deleting a standing area. When the `undo()` function is called, actually a new `DeleteStandingAreaAction` is created, and its `execute` is called, because it implements the correct business logic for undoing the action. Same is true for the call of the `undo()` function in the `DeleteStandingAreaAction`. With this code both functionalities can be implemented by separate buttons or something similar, and the undo and redo functionality is implemented as well. The needed contexts and functions to execute the business logic correctly for both classes can be defined individually in the constructor of the classes. The class also has to store the information

to undo its actions, for example the move action has to store the old position of the object to be able to move it back to the old position.

The actual undoing logic is defined by a controller. When an action should be undo and redoable it has to be passed to the controller. The controller manages the function and can be called to undo or redo the last action. It also manages the stack of actions, so that all the actions can be undone and then redone again, until a new action is executed. When this happens the controller ignores all of the “future” actions that would have come after the current action. For example: Action1, Action2, Action3 and Action4 have been executed. The latest action saved by the Controller is currently Action4. Currently, all the actions can be undone and then redone in a stack like way. This means Action4 is undone, then Action3, then Action2 and so on. Then they can all be reapplied in the same reversed order. When actions have been undone, to Action2 for example, and then a new Action5 is executed, Action3 and Action4 will be scrapped, because a new “future” has been created. This is a common behavior in undo and redo functionalities.

The implementation of the controller is as shown in listing 19.

Listing 19: Action controller implementation

```

1  const loopSize = 50;
2  const actionHistory: (Action | undefined)[] = new Array(loopSize).fill(undefined);
3
4  let historyIndex = 0;
5  let maxIndex = 0;
6  let minIndex = -1;
7  let savedIndex = 0
8
9  const loopSize = 50;
10 const actionHistory: (Action | undefined)[] = new Array(loopSize).fill(undefined);
11
12 let historyIndex = 0;
13 let maxIndex = 0;
14 let minIndex = -1;
15 let savedIndex = 0
16
17
18 const doAction = (action: Action) => {
19     historyIndex = increase(historyIndex);
20
21     while (maxIndex !== historyIndex) {
22         actionHistory[maxIndex] = undefined
23         maxIndex = decrease(maxIndex)
24     }
25
26     actionHistory[minIndex] = undefined
27     minIndex = increase(maxIndex);
28     actionHistory[historyIndex] = action;
29     action.execute!();
30     checkForUnsavedChanges()
31 };
32
33 const updateSaveIndex = () => {
34     savedIndex = historyIndex
35     checkForUnsavedChanges()
36 }
37
38 function increase(num: number): number {
39     return num !== loopSize - 1 ? num + 1 : 0;
40 }

```

```

41
42 function decrease(num: number): number {
43     return num !== 0 ? num - 1 : loopSize - 1;
44 }
45
46 const undo = () => {
47     if (historyIndex !== minIndex && actionHistory[historyIndex] !== undefined) {
48         actionHistory[historyIndex]!.undo!();
49         historyIndex = decrease(historyIndex);
50         checkForUnsavedChanges()
51         enqueueSnackbar("Undone", {variant: "info"})
52     }
53 };
54
55 const redo = () => {
56     if (historyIndex !== maxIndex && actionHistory[increase(historyIndex)] !==
57         undefined) {
58         historyIndex = increase(historyIndex);
59         actionHistory[historyIndex]!.execute!();
60         checkForUnsavedChanges()
61     }
62 };
63 const getCurrentAction = (): Action | null => actionHistory[historyIndex] ?? null;

```

To register a new Action in the controller, the `doAction` function has to be called with the action as a parameter like in this listing 20. The context referenced here is the context containing business logic for the map as well as containing the logic for the undo and redo controller.

Listing 20: Registering a new action in the controller

```

1 context.doAction(new AddSeatAction(context.setSeats, lat, lng))

```

This controller stores all the actions in the form of a loop, with the size defined by the `loopSize` variable. The variable is set to 50 because more than 50 undoable actions back are not necessary. A circular buffer for storing this kind of data is very advantageous because when the buffer is full, the oldest action is overwritten by the newest action because the oldest data is not needed anymore. Other very important variables are the `minIndex` and `maxIndex` variables. They define the range of the actions that can be undone and redone. When undoing, it's checked that the current index which is represented by the `historyIndex` is not the same as the `minIndex` and there is also an undoable action, because then there would be no more actions to undo. Only if these conditions are fulfilled, there are actions to undo, and the `undo()` this is called, and the `historyIndex` is decreased. A similar logic is applied for the `redo()` function, but with the `maxIndex` and the `increase()` function. The `doAction()` function is used to handle new actions. It increases the `historyIndex` and sets the `maxIndex` to the `historyIndex` and overwriting all the no longer needed Actions with undefined. The `minIndex` is set to the `increase(maxIndex)` to ensure that when the loop is full, that the changes that are too old they are removed. At last the action is added to the list of actions and the `execute()` function is called.

The `increase()` and `decrease()` functions are used to increase and decrease the index in a circular way. This is necessary because the buffer is circular and when the end of the buffer is reached, the index has to be set to the beginning of the buffer again. This is done by checking if the index is at the end of the buffer and then setting it to the beginning of the buffer again.

4.10.2 Tools

Tools played a significant role during development, making it essential to ensure that the implementation of new tools was as easy and fast as possible. To achieve this, a Tool interface was designed, where instances only need to be added to an existing array containing the tools. The final version of this interface is presented in Listing. 21.

Listing 21: Tool interface

```
1 export interface Tool {  
2   id: string  
3   icon: ReactNode,  
4   onSelect?: ()=>void,  
5   hotkey?: string  
6 }
```

The attributes of the interface are the following:

- **id**: The id, which is used to identify the tool. Normally this is a string which is the name.
- **icon**: The icon of the tool, which is displayed in the toolbar. This has the type `ReactNode` because first a simple string was used, to pass it to an icon component, but then it was decided to use the `ReactNode` type, because it's more flexible, and the icons are not only limited to the icons of one UI library, but any icon can be used, including SVG icons.
- **onSelect**: The function that is called when the tool is selected. This is optional because not every tool needs a function to be called when it's selected. Some tools are handled externally.
- **hotkey**: The hotkey is a string that defines the hotkey for the tool. This is optional because not every tool needs a hotkey.

In listing 22 list of all the implemented Tools and how they look, when the corresponding image 10 of how they are rendered.

Listing 22: Implemented Tools

```
1 const tools: Tool[] = [  
2   {
```

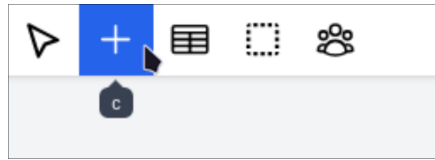


Figure 10: Tools in SeatGen

```

3      id: "mouseTool",
4      icon: <svg viewBox="0 0 24 24" xmlns="http://www.w3.org/2000/svg">
5          <path
6              d="..."
7          />
8      </svg>,
9      onSelect: () => handleToolSelect(() => {
10     }, "mouseTool", "default"),
11     hotkey: "v"
12 },
13 {
14     id: "addTool",
15     icon: <PlusIcon></PlusIcon>,
16     onSelect: () => handleToolSelect((e) => {
17         props.addSeat(e.latlng.lat, e.latlng.lng)
18     }, "addTool", "cell"),
19     hotkey: "c"
20 },
21 {
22     id: "addGridTool",
23     icon: <TableCellsIcon></TableCellsIcon>,
24     onSelect: () => handleToolSelect(() => {
25     }, "addGridTool", "cell"),
26     hotkey: "g"
27 },
28 {
29     id: "squareSelectTool",
30     icon: <svg xmlns="http://www.w3.org/2000/svg" viewBox="0 -960 960 960">
31         <path
32             d="..." />
33     </svg>,
34     onSelect: () => handleToolSelect(() => console.log("Clicked"),
35         "squareSelectTool", "crosshair"),
36     hotkey: "a"
37 },
38 {
39     id: "standingAreaTool",
40     icon: <UserGroupIcon />,
41     onSelect: () => handleToolSelect(() => console.log("standingtool"),
42         "standingAreaTool", "crosshair"),
43     hotkey: "s"
44 }
45 ];

```

The `handleToolSelect` function is a function that is called when a tool is selected. It's responsible for setting the current tool and the cursor as shown in listing 23. The cursors supported are the names of all the cursors names supported by the browser. These can be viewed on the Mozilla developer documentation [13].

Listing 23: Handle tool select function

```

1  const handleToolSelect = useCallback((toolFunction: (e: LeafletMouseEvent) =>
2    void, toolId: string, cursorIcon?: string) => {
3    const cursorName =
4      L.DomUtil.getClass(props.map.current!.getContainer()).split(" ").find((it)
5        => it.startsWith("cursor-"));
6    if (cursorName) {
7      L.DomUtil.removeClass(props.map.current!.getContainer(), cursorName);
8    }
9    if (cursorIcon !== undefined) {
10     L.DomUtil.addClass(props.map.current!.getContainer(),
11       `cursor-${cursorIcon}`);
12   }
13 }

```

```
9      setActiveToolFunction(() => toolFunction);  
10     context.setSelectedToolId(toolId);  
11 }, [props.map, setActiveToolFunction]);
```

After all this is set, the tools are simply rendered with a component, that handles all these properties like hotkeys and the icon.

4.10.3 Backend Services

For the backend services SeatGen uses a very general and exchangeable approach that works with Spring. For the services, an interface is defined, which is then implemented by the respective service classes. This interface is used to define the methods that are needed for the services. In the controller the service is injected, and spring automatically creates an instance of the correct service implementation and injects it into the controller. This is a very common approach in Spring and is used in many projects.

5 Summary

5.1 Michael Ruep

5.2 Michael Stenz

For my part I was responsible for most of the technology choices in the backend and some design choices in the frontend. All these choices had a huge impact on the entire development of the application because some featured centered around these libraries and patterns. In my opinion some choices were very good, but some choices probably weren't the most optimal as stated in the thesis, like java vs python for the backend. A big limitation were the technology demands of the Solvistas company, but it's important to also address these challenges and to find solutions that fit the company's needs. I personally learned a lot of new patterns that are used in the industry and I think that this new knowledge can be very useful in future projects. When it comes to splitting the tasks, it was a very smooth process because my partner and I had a very good communication and were able to both work on the tasks and tools that fitted more our expertise and interests. Also, after the minimal implementation of the project had been done, we were able to expand it feature by feature very easily because in the end the project more or less looked like a small framework, with all the patterns that enabled this easy expandability. A big takeaway from this project is that it can be overwhelming at first when working with huge libraries like Leaflet. When dealing with these challenges it's very important to start with a small prototype and read the documentation very carefully because most of the time the solution is hidden somewhere in the documentation, and a lot of time can be saved when reading it instead of trying to figure out the solution by yourself.

The decision to collaborate with a company was both good and bad in different aspects. On the one hand, it was very good because we were able to get a lot of feedback from the company, and we were able to address a real-world problem. On the other hand a part of our task was to understand parts of the Ticketing project which has a huge codebase, and we also had to understand code of the csv-stadium-creator tool and the

workflow of the employees that are responsible for the maintenance and creation of the stadium.

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Appendix