

Airport Landside Design: A Parametric Approach

MSc Thesis

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Airport Landside Design: A Parametric Approach

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the degree of*

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by

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Cover: Image of the new CPK airport in Poland by Foster + Partners and
NACO (Partners and NACO, 2022)

Preface

Before you lies my master thesis “Parametric Modelling of the Airport Landside of Passenger Terminals”, written in partial fulfilment of the Master’s program Transport, Infrastructure and Logistics at Delft University of Technology. This research was conducted in collaboration with NACO (Netherlands Airport Consultants), a company of Haskoning, and marks the end of my time as a student at the TU Delft.

Over the past months, I have had the opportunity to work on a interesting subject in airport planning, the parametric modelling of the landside with a focus on the integration of public transport. It has been a challenging task to generalise the complex landside systems to make it parametrisable. Working on this topic allowed me to combine my interests in aviation, logistics, and parametric design.

I would like to thank my TU Delft supervisors, Maria Salomons and Paul Roling, for their guidance and feedback throughout the project. I would also like to thank Niels van Oort for his feedback during the milestone meetings. A special thanks goes to Barth Donners and Peter Rieff for introducing me to NACO and for their valuable insights and practical perspective during the research. Finally, I would also like to thank my colleagues at NACO for always being open to my questions and the pleasant work environment they created.

I hope this thesis provides a meaningful contribution to the discussion on how parametric and integrated design approaches can improve future landside development.

I wish you an enjoyable read.

*F.A.J.C. (Floris) Muis
Delft, December 2025*

Summary

Airports are complex systems where passenger experience, operational efficiency, and multimodal connectivity come together. The design of the landside areas, which are the interface between passenger terminals and the external transport, has a significant impact on accessibility and efficiency. Traditionally, landside planning relies on static forecasts and "rules of thumb" provided by IATA, ICAO, and ACRP. These industry guidelines offer general capacity standards and level-of-service criteria, but they are based on fixed assumptions and lack flexibility, which can lead inefficient landside designs.

Project timelines in airport design are increasingly under pressure, which makes it essential to quickly explore and evaluate alternative landside configurations during the early design stages. This reveals a knowledge gap: current methods do not allow planners to efficiently test different layouts or assess the impact of changing demand and design priorities. Addressing this gap requires a more structured and transparent approach to early-stage airport landside design.

This thesis, conducted at the Delft University of Technology in collaboration with NACO (Netherlands Airport Consultants) part of Haskoning, investigates how parametric design can support early-stage airport landside design. A parametric model was developed that generates, optimises, and evaluates landside configurations dynamically, enabling planners to test different scenarios rapidly. This can provide a more structured and transparent approach for airport landside planning, supporting multimodal integration, improving passenger experience, and bridging the gap between conceptual design and strategic decision-making.

The research focused on three main topics to improve early-stage landside planning:

- **Current practice**

Literature and expert consultations showed that design depends on "rule of thumbs" and peak-hour demand, which limits quickly testing different layouts. Literature also showed the potential of parametric design in other fields and that the implementation of such parametric tools is missing in the landside planning context right now. Passenger experience can be represented through: walking distance, level changes, conflict points, and passenger flow separation.

- **Performance parameters**

Three parameter groups were identified, demand (passenger flow, modal split), spatial (geometry and configuration), and performance (objective value, walking distance). Walking distance reflects passenger experience in the parametric model because it is easy to quantify and usable in 2D optimisation. Level changes and conflict points, are not in the parametric model because this would require adding a 3D component, complicating the modelling too much.

- **Parametric design**

A parametric model was developed to generate and optimise landside layouts dynamically. Rhino provides 3D modelling, Grasshopper allows parametric relationships between elements, and Galapagos (an annealing solver) optimises layouts to minimise weighted walking distances. The approach allows planners to explore alternative scenarios using Excel data, however the outputs are not yet of sufficient quality that they are directly ready for implementation.

Grasshopper provided two built-in solvers, both the evolutionary solver and the annealing solver were tested. The annealing solver was used because it explored the solution space broader and the solver provided more consistent and higher-quality solutions across the different iterations. The model was tested with the following five scenarios: Base, High Demand, Modality Preference, Mode Fixed Position, and No Arrival Kerb. The model results from the different scenarios show logical trends: higher demand increased surface requirements and walking distances, while removing the arrival kerb resulted in more compact and efficient layouts. The parametric model produces realistic, interpretable designs in a reasonable time, which allows planners to explore alternatives more efficiently than by using the conventional methods which require a lot of iterations and repetitive steps.

The study provided several insights into the potential and limitations of parametric design for landside planning. The first step of the parametric model is to visualise and structure the raw Excel input data, translating it into 2D visuals of the landside structures. The second step of the parametric model showed that the locations of the landside structures could be optimised based on walking distances by a solver, but it also revealed practical challenges in Grasshopper. As more landside elements, degrees of freedom, and overlap conditions were added, the problem space grew quickly, which made convergence more difficult and the results less reliable. This showed that the strength of parametric model is maybe not in the automated location optimisation of the landside structures, and that this step of location determination is still maybe a better task for the airport planners themselves. The opportunities lie the third step of the parametric model which is supporting the airport planners with an interactive analysis of layout alternatives. In this case manual expert input is still necessary to evaluate and improve the the design outcomes.

In conclusion, parametric design can transform landside planning from a static process into a more adaptive and data-driven approach. In theory, the model allows planners to explore multiple layout alternatives quickly, generating designs in minutes rather than the hours or days required by using conventional methods. While the resulting layouts are broadly comparable to traditional designs, the main benefits are flexibility, scenario testing and transparency. While the model is limited to 2D layouts, it provides a foundation for future research to make more advanced, multi-level planning tools.

Recommendations for further research are mostly focussed on the second step of the parametric model, exploring alternative location optimisation algorithms inside or outside of Grasshopper. For NACO, the focus should be more on the third step of the parametric model, expanding the passenger experience to include level changes and conflict points by integrating a 3D component. Besides that, the tool could also be more generalised for multiple airports or specified for specific terminal typologies.

Overall, this thesis offers a first parametric model for optimising the landside layout, as well as some insights into how early-stage landside planning might benefit from models like this. The approach primarily enhances the speed, transparency, and flexibility of the exploration of alternative designs. However, the model has its limitations regarding the simplified representation of reality without a 3D component. It is not directly of use for NACO right now because certain steps still need to be taken in the implementation of the model. This research can form the basis for more holistic, passenger-centric applications in future research focussing on the provided recommendations.

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1

Introduction

1.1. Context

As global air travel continues to grow, airport infrastructure is under increasing pressure to accommodate higher passenger volumes, more diverse traveller needs, and a greater focus on sustainability. In airport design there is much focus on airside capacity and terminal interiors, while the landside is of equal importance in shaping the performance and accessibility of the airport. The landside includes the access roads, kerbside, parking facilities, and public transport connections. For the landside of passenger terminals it is important that they are designed to handle increasing capacity efficiently while maintaining a high Level of Service (LoS).

Given the complexity and growing demand for integrated transport solutions, there is a need for innovative approaches that treat the airport landside as an adaptable and interconnected system, one that considers a range of influencing factors such as demand uncertainty, transfer passenger share, and multimodal access availability. Traditional design approaches can lack adaptability and integration between landside design and public transport. This can lead to inefficiencies in space utilization, passenger flow, and public transport accessibility. Poor integration between the terminal and public transport systems can lead to congestion, reduced passenger convenience, suboptimal operational efficiency and a restriction to airport growth. This research seeks to bridge these gaps by integrating KPIs like, walking distance and capacity into a parametric model approach. This will allow faster testing of landside layouts for passenger terminals that can adapt to varying demand and design inputs.

1.2. Research Gap

The majority of airport landside planning is still done using static forecasts and “rules of thumb” to predict spatial and operational needs. Although this method is straightforward, it lacks flexibility and precision, often leading to inefficiencies (Dimitriou et al., 2025, Jones and Pitfield, 2007). There are two important reasons why this issue is becoming increasingly important. First, airports have to align with broader sustainability goals, which require a shift away from car dependency toward more sustainable transport modes. Second, expanding road infrastructure is becoming increasingly constrained by space limitations, making entirely relying on car access unsustainable in the long term. Furthermore, the physical integration of public transport is not embedded well enough in the design process, although it is becoming increasingly important for reducing car use and improving connectivity (Fang and Zimmerman, 2015, Mrníková et al., 2017).

Recent developments in parametric and generative design offer potential to improve the design process. These methods allow faster testing of alternatives and better adaptation to future changes, but have not been well implemented to the landside context (Zografos et al., 2010, Sitek and Maśły, 2018). However, there are enough interesting methods used in other fields to look at (Weber et al., 2022, Laignel et al., 2021, Jiang et al., 2024, Bielik et al., 2022). This highlights an interesting knowledge gap: the absence of a data-driven tool, like a parametric model, for landside planning that includes the physical integration of public transport.

1.3. Research Objective

The main objective of this research is to develop a structured approach for the design of airport landsides of passenger terminals based on key performance indicators (KPIs) and benchmarking. The goal is to develop a parametric model that enables adaptable, data-driven configurations based on demand forecast data, while ensuring that public transport is physically well integrated in the landside infrastructure.

1.4. Research Scope

This research is focused on the design and planning of landside infrastructure of airport passenger terminals, and this includes, but is not limited to:

- Airport roadways
- Kerbside layout
- Parking facilities
- Car rental facilities
- Public transport integration (rail, MRT, bus)
- Key external factors such as transfer passenger and modal split

The internal terminal components on itself, such as check-in, security, and baggage claim, are outside the scope of this research, as well as the design of the stand-alone public transport stations. The focus remains on airports, where unique conditions, such as the terminal configuration, flight wave scheduling, transfer passenger behaviour and multi-modal demand peaks, create specific landside planning challenges. Not all airport landside infrastructure is relevant for this research, only the infrastructure in front of the passenger terminal will be taken into account. So infrastructure like cargo terminals, long-term parking and other remote locations are out of the scope of this research. For the airport landside infrastructure it is important to determine whether there is a central or decentralized layout with one or more headhouses.

This research does not particularly focus on brownfield or greenfield airport projects. Greenfield airports are entirely new developments built on undeveloped sites, while brownfield airports are expansions or redevelopments of existing airports. In both cases, the existing or surrounding infrastructure sets boundaries for what is possible. This includes, the location and number of runways, the main access roads, the position of the airport in the public transport network, and other urban development factors.

The model will use a "blank canvas", where only the location of the terminal building and boundaries of the landside are used as input. For greenfield airports it is easier to create this "blank canvas" than for brownfield airports. Considering the duration of this research and to reduce the complexity, the brownfield situations will be simplified. The simplified brownfield settings will consist of the current situation that has been emptied, only important boundaries and fixed infrastructure will serve as input, resulting a "semi-greenfield". For both instances, the model will configure layouts for the optimal situation based on important parameters and KPIs. The main goal is to support the complex decision-making when designing the landside, where trade-offs and different design alternatives must be carefully evaluated.

The desired outcome of this research is the development of a parametric model to generate airport landside configurations and the physical integration of public transport.

1.5. Research Questions

The aim of this research is to explore how a parametric model can be used in the design process of the airport landside of passenger terminals, with a specific focus on the physical integration of public transport. The goal is to improve the design process of the landside design by making the generation of alternatives faster, for this flexibility and transparency are important factors. To achieve this objective, the following main research question will be addressed:

In what way can a data-driven parametric model make the design and evaluation of airport landside configurations more flexible and adaptive?

1. How are airport landside structures for passenger terminals currently sized and designed, and which design rules can serve as input for a parametric model?
 - (a) How does a typical landside look like for passenger terminals?
 - (b) What are the traditional methods for the design of the airport landside?
 - (c) How to size the various landside structures based on peak hour demand?
2. What are the key design parameters for modelling airport landside performance, with particular attention to passenger experience?
 - (a) Which parameters should be included in a parametric model for airport landside design, and how can they be translated into usable model inputs?
 - (b) How can passenger experience be expressed and quantified?
 - (c) To what extent can generative design methods from other fields be adapted to enhance parametric design for airport landside planning?
3. What is needed for a parametric model to generate airport landside configurations based on different scenario inputs, and how can these be evaluated?
 - (a) What data is needed to parametrise airport landside designs?
 - (b) How can the parametric model generate and optimise alternative landside configurations based on scenario inputs?
 - (c) How can the generated alternative landside configurations be evaluated?

1.6. Thesis Outline

This thesis is structured to guide the reader from the research motivation to the development and evaluation of a parametric model for airport landside planning. Chapter 1 introduces the research topic, objective, scope, and the main research question, along with the sub-questions that will help structure the research. Chapter 2 describes the research methodology, outlining the overall approach and methods used, the framework of the tool, and the expected outputs. Chapter 3 offers a structured literature review covering the following key domains: current practices in landside planning, decision support tools, generative design and passenger experience. Chapter 4 presents a system analysis of the airport landside, providing a detailed overview of the landside structures, demand groups, system constraints and interactions. Chapter 5 presents the model specification, explaining the model structure and scenario generation logic. Chapter 6 presents the model outcomes, looking at different scenarios and optimisation process. Finally, Chapter 7 presents the conclusion based on the findings, discusses their broader implications, and presents recommendations for future research. A scientific paper summarising the research is included in Appendix B.

2

Research Methodology

2.1. Introduction

This chapter presents the research methodology and is structured as follows: Section 2.2 presents and describes the methods used to answer the sub-questions. Section 2.3 shows the overall framework which contains the parametric model. It presents the step-by-step process that begins with the forecast and ultimately leads to the evaluation and optimisation of the airport landside configurations. Section 2.4 describes what the output of this research will be.

2.2. Research Methods

This section describes the approach that is used to answer the main research question. Table 2.1 provides an overview of the sub-questions and the methods that are used to answer these sub-questions. The subsections provide a more detailed explanation on the used methods and explain there role in the research process.

Table 2.1: Sub-questions and corresponding methods

Sub-Question	Method
1. How are airport landside structures for passenger terminals currently sized and designed, and which design rules can serve as input for a parametric model?	Literature review and expert consulting
2. What are the key design parameters for modelling airport landside performance, with particular attention to passenger experience?	Literature review and expert consulting
3. What is needed for a parametric model to generate airport landside configurations based on different scenario inputs, and how can these be evaluated?	Data exploration and parametric modelling

Literature Review

The literature review provides the theoretical foundation for the research. It combines the knowledge from academic studies, airport planning guidelines, and standards related to the design of the landside of passenger terminals and public transport integration. The goal is to understand the existing state of how the airport landside systems are currently designed, how they perform, and how public transport is integrated into the landside infrastructure. The review is also used for the identification of relevant design parameters, KPIs, and modelling strategies.

Expert Consulting

Expert consulting with airport planners and architects at NACO will complement the literature review by providing practical insights into how landside planning is done and how public transport is integrated in real projects. These discussions help to capture aspects that are often not found in guidelines, such as trade-offs in layouts, dealing with uncertainty, and balancing stakeholder interests. The input from the expert consulting also supports the selection of relevant design parameters and KPIs, and helps to make sure the parametric model aligns with practice.

Data Exploration and Analysis

To create a parametric model, it is necessary to determine which parameters are relevant and also measurable. This step involves exploring the available datasets within NACO to identify what data is relevant and realistically can be used. The suitable datasets will be prepared for use in the model and simplified or adapted where necessary.

Parametric Modelling

The main part of the research lies in developing a parametric model that can generate several landside configurations based on different scenarios. The model is developed around a set of layout principles and design parameters identified in previous steps of the research. It generates several landside configurations and says something about their performance by looking at the the passenger experience which, for this research, consists of only the walking distance. To support the parametric design approach, this research uses a combination of Excel, Python, Grasshopper, and Rhino. These tools were selected because they align with existing NACO workflows. The airport planners use Excel for demand-based sizing, while part of the architects work with Rhino and Grasshopper. Using tools already familiar within the organisation ensures that the method remains transparent, reproducible, and suitable for future internal use.

2.3. Tool Framework

Figure 2.1 presents the overall framework which contains the parametric model. The framework shows a step-by-step process that begins with the forecast and ultimately leads to the evaluation and optimisation of the airport landside configurations.

Input: From Flight Schedule to Capacity Requirements

The process starts with the **forecast**, which defines the expected MAP (Million Annual Passengers) and air traffic movements. This is needed for calculating the **passenger demand**, consisting of origin/destination (O/D) passengers, transfer passenger percentage, and peak hour demand. The passenger demand together with the **employee demand** are important inputs for the **modal split**. The modal split is applied to estimate the share of travellers using different access modes. This leads to a detailed **demand profiling**, identifying peak-hour volumes. Based on this modal split and the **database**, which present realistic value ranges based on reference data from similar reference projects, the **landside capacity requirements** are calculated. These include needed kerb length, parking capacity, road capacity, number of public transport platforms, and other physical infrastructure demands.

Core Modelling Logic: Parametric Tool and Scenario Configurations

The landside capacity requirements serve as input for the **parametric model**. The parametric model performs a single-objective optimisation based on passenger experience, where passenger experience consists of the walking distance. The output of the model is the **landside configuration**, which is generated by the model for a given scenario input. Each configuration consists of a landside layout, objective value, and important KPIs. Instead of letting the model determine the location and/or size of the different landside structures, it is also possible to make use of a **manual input**. In this case, the user determines the location of the landside structures, allowing the parametric framework to generate the corresponding objective value and KPIs. This enables the creation of manually produced layouts alongside the automatically optimised layouts.

Scenario Evaluation and Feedback Loop

After the model or manual input generated the landside configuration, a **performance evaluation** is conducted. The landside layouts, the objective value and the key performance indicators (KPIs) which represent the passenger experience are compared to each other. Based on this evaluation, **design adjustments** can be made to improve the outcome. A **feedback loop** shows where the user can modify the input. This should be done at the part where landside capacity requirements are decided, or all the way back at the beginning where the original flight schedule is provided.

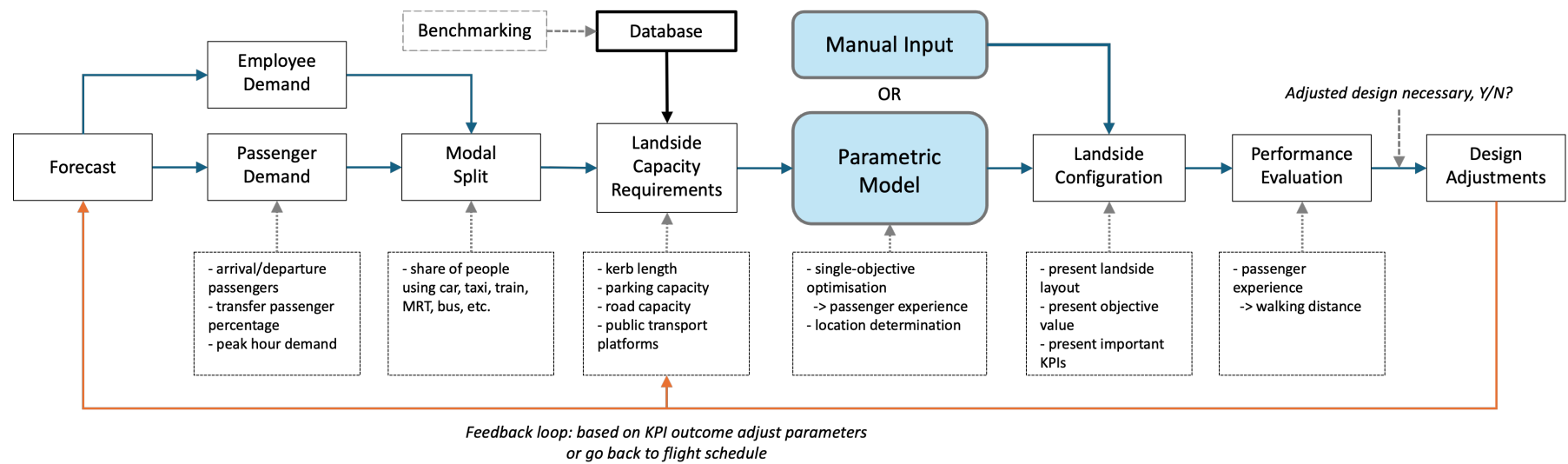


Figure 2.1: Framework of the Parametric Decision Support Tool for airport landside design

2.4. Output (product)

The main products of this research are the master thesis report, along with a scientific paper (included in Appendix B). The thesis report documents the theoretical background, methodological development, model formulation, model outcomes, and conclusions and discussions of the study.

In addition to the master thesis report, the research produces a basic functional parametric model for the planning of airport landside infrastructure of passenger terminals. This tool is designed to assist airport planners and decision-makers in generating and evaluating alternative landside configurations.

The following product is developed:

- A functional parametric model using real-world data, implemented in Rhino/Grasshopper and capable of generating different layout configurations, calculating key performance indicators

The tool consists of:

- An Excel file to enter demand profiles, modal splits and other important parameters
- A Rhino/Grasshopper file which uses the data from the Excel file to generate different layouts
- A visual and numerical output which shows landside configurations and the key performance indicators (KPIs) of the different layouts

For the developed model, a basic user manual or short implementation guide will be made to enable NACO or other stakeholders to look into or expand the tool beyond the scope of this thesis.

From a scientific perspective, this research combines generative design principles with parametric modelling in the specific context of airport landside infrastructure. It adds to the existing body of knowledge on data-driven early stage planning by creating an adaptable and easily accessible model that integrates demand, spatial, and public transport parameters. Furthermore, the research shows how the parametric model is created and what considerations are made, offering a replicable methodology for infrastructure planning beyond the aviation sector.

Together, these outputs aim to contribute to a more structured and transparent approach for airport landside planning, bridging the gap between early stage design and strategic decision-making. By automating repetitive design tasks and offering quick scenario testing, this approach can reduce the time needed to explore alternative layouts, while providing data-driven insights to support informed decision-making.

3

Literature Review

3.1. Introduction

This chapter presents the literature review conducted and is structured as follows: Section 3.2 explains the search strategy used to identify and select relevant literature. Section 3.3 presents a literature overview examining the existing knowledge on the design and decision-making processes in the context of landside development of air passenger terminals. This overview will serve as a starting point for the more extensive literature review in section 3.4 looking at parametric design and section 3.5 looking at passenger experience. Together, these sections provide the knowledge required to define the key inputs and assumptions for the parametric model developed later in this research. The chapter wraps up with a summary.

3.2. Search strategy

The aim of the search strategy is to find relevant literature about the design and planning of the landside of air passenger terminals. Doing this will help to gain a better understanding of the current state of knowledge about the subject. The concept groups shown in Table 3.1 are used in different truncations to find relevant papers. To include the literature, it has to satisfy the following criteria: first, it has to be published as an article in an academic journal; second, it has to be published within the last twenty years; third, the subject has to meet the concept groups or key words. Papers were added to the literature list based on the relevance of the abstract, discussion and conclusion, while also taking into consideration the limitations and recommendations for further research. Furthermore, by making use of forward and backward snowballing relevant papers can be found while staying within the scope.

Table 3.1: Conceptual and methodological framework for literature review

Concept Groups	airport landside; public transport integration; decision support tool; parametric design; passenger experience
Keywords	<u>airport landside:</u> terminal access, landside layout, sizing, curbside, parking, access roads <u>public transport integration:</u> airport connectivity, intermodal access, air-rail integration, multimodal hub <u>decision support tool:</u> decision support tool, simulation model, infrastructure planning, scenario planning, reference class forecasting <u>parametric design:</u> generative design, design automation, Python, Grasshopper, Rhino <u>passenger experience:</u> Level of Service, walking distance, accessibility, KPIs, benchmarking
Truncation	"airport landside" OR "airport" OR "terminal access" AND "public transport integration" OR "intermodal access" OR "multimodal hub" AND "decision support" OR "scenario planning" AND "parametric design" OR "generative design" AND "passenger experience"

3.3. Literature Overview

This section presents a literature overview examining the existing knowledge on the design and decision-making processes in the context of landside development of air passenger terminals. This overview will serve as a starting point for the more extensive literature review in section 3.4 looking at parametric design and section 3.5 looking at passenger experience.

3.3.1. Analysis

Airport Landside

The design of the airport landside traditionally relies on annual passenger forecasts and peak-hour demand estimates to provide guidelines for the terminal design and operational decisions. Airport landside infrastructure requires large investments, so it is important to provide the capacity that best meet the demand. This depends on at least two factors, the accuracy of the forecasts of future demand and how the forecasts are translated into designs (Dimitriou et al., 2025). How these forecasts are translated into designs depend on “rule of thumb” formulas, where design hour flows are converted to area requirements. Creating a methodological framework for landside development can be a good option to guide the airport landside development (Jones and Pitfield, 2007). However, conventional methods have some limitations in accurately translating forecasts into requirements, often resulting in inefficiencies and suboptimal resource allocation. At present, no comprehensive tool exists for designing a coherent landside with a particular focus on public transport integration. The design process of the landside now mainly consists of designing the different systems of the landside separately. A more dynamic, data-driven approach that can help with the design and planning of the landside would be a great addition.

Public Transport Integration

Integrating public transport access into airport landside planning is becoming increasingly important for improving connectivity and reducing congestion. Effective integration of public transport is seen as a way to compete with the use of private vehicles (Mrníková et al., 2017). In general, public transport attracts the largest number of users and is most efficient and successful when it is planned and operated as a seamless, integrated system. Two integration dimensions must be taken into account, the integration of all modes and routes that make up the multi-modal public transport network, and integration of the physical and operational components of each individual mode and service (Fang and Zimmerman, 2015). Successful integration will help increase public transport usage, will make public transport more competitive compared to private vehicles and will help increase customer satisfaction.

Decision Support Tool

Recent developments highlight the use of parametric and simulation-based decision support tools to maximise terminal operations. Right now, airport planners lack decision support tools that can provide an integrated overview of the total airport landside and analyse the various trade-offs between the different airport key performance measures. To capture the various aspects of airport performance, the assessment requires the use of advanced modelling capabilities and decision support systems or tools (Zografos et al., 2010). Some research has been done on different methodologies that look at programming the size of the functional zones of airport terminals. There are currently tools in development that can transform numerical data to different forms based on specified geometrical criteria and their arrangement in relation to each other Sitek and Masly, 2018. However, no real studies have been done on how this could be applied to the landside. Parametric methods can further improve decision-making by allowing quick testing of different options, supporting more informed and adaptable designs.

Parametric Design

Parametric and generative design approaches are increasingly used in other fields to optimise the spatial and functional layout of floor plans, urban design and master plans. The generative design methods are mostly used in the architectural context in projects of different scales. At a higher level of detail, there is plenty of research to be found on automatic floor plan layout generation methods (Weber et al., 2022) and on automatic apartment layout generation methods (Laignel et al., 2021). These methods can quickly generate several designs which help with the optimisation and creation of new buildings. At a lower level of detail, there is also enough of research to be found. Generative urban design (GUD) produces design solutions with high efficiency at early design stages, it uses methods like evolutionary optimisation and deep generative models (Jiang et al., 2024). At an even lower level of detail various generative and analytical methods can be used to create adaptive master plans (AMPs), where the designer can change the input parameters and explore their effects on the resulting design (Bielik et al., 2022). To process statistical and computational data into visual representations, these methods can also be applied to explore different design options and their impact on capacity and passenger experience of landside of air passenger terminals. Tools such as Grasshopper and custom algorithms can help airport planners to iteratively test and refine design solutions, ensuring that landside layouts remain adaptable to changing demands and standards. Grasshopper is a visual programming tool within the 3D modelling software Rhino, that enables users to create parametric models without traditional coding. Parametric and generative design also support the integration of public transport by allowing airport decision makers to model and optimise passenger flows from various access points.

Passenger Experience

Passenger experience at airports is determined by how efficiently and comfortably passengers can deal with landside operations, including entrance, arrival, wayfinding and interaction with public transport. The IATA Airport Development Reference Manual (ADRM) provides the foundational industry standards for designing the landside elements, highlighting level-of-service criteria such as: spatial comfort, queueing performance and intuitive wayfinding that directly impact passenger experience International Air Transport Association, 2022. According to recent research on multimodal travel, passengers favour predictable transfers, straightforward paths, and streamlined information across modes when moving from public transport to the terminal Boersma, 2025. At the same time, studies of airport experience highlight that passengers assess their journey very broadly, combining functional aspects (processing times, baggage, kerbside access), emotional factors, and environmental satisfaction. However, many components are beyond the scope of strictly landside facilities Jiang and Zhang, 2016. These findings highlight the importance of landside planning in terms of both operational performance and personal experience, making sure that access, inter-modality, and user expectations are aligned from the moment passengers arrive at the airport.

3.3.2. Conclusion

The majority of airport landside planning is still done using static forecasts and “rules of thumb” to predict spatial and operational needs. While rules of thumb are useful for quickly generating conceptual designs, they rely on standardised assumptions and simplified relationships, which limits the ability to adapt to site-specific conditions or explore a wide range of design alternatives (Dimitriou et al., 2025, Jones and Pitfield, 2007). Public transport integration is not embedded well enough in the design process, although it is becoming increasingly important for reducing car use and improving connectivity (Fang and Zimmerman, 2015, Mrníková et al., 2017). Another important factor that should be embedded in the design process is the passenger experience. Industry standards can be found in the IATA Airport Development Reference Manual (ADRM) (International Air Transport Association, 2022) and there should be looked at the findings from researches that focus on the inter-modality (Boersma, 2025) and all the components that contribute to passenger experience (Jiang and Zhang, 2016).

Recent developments in parametric and generative design offer potential to improve this process. These methods allow fast testing of alternatives and better adaptation to future changes, but have not been well implemented to the landside context (Zografos et al., 2010, Sitek and Masły, 2018). However, there are enough interesting methods used in other fields to look at (Weber et al., 2022, Laignel et al., 2021, Jiang et al., 2024, Bielik et al., 2022).

This highlights an interesting knowledge gap:

“the absence of a flexible, data-driven parametric tool for landside planning of passenger airport terminals”

3.3.3. Discussion

The knowledge gap, the absence of a flexible, data-driven parametric tool for landside planning of passenger airport terminals, that also allows fast testing of different alternatives, is highly relevant for airport master planning. A lack of integrated data-driven tools limits the ability to make quick informed decisions for landside designs. A parametric decision support tool could help airport planners to quickly test different layout alternatives and public transport scenarios, making the design process more adaptive.

For NACO, the practical relevance lies in improving the early design phase. The focus on the early design phase is because the parametric tool is designed to explore different layouts and test design scenarios before detailed engineering and operational constraints are determined. In later design phases, the design is constrained by finalised infrastructure, detailed schedules, and regulatory requirements, this provides fewer possibilities for iterative layout exploration. Right now, there is not such a tool that covers the landside as a whole, the design process mainly consists of separate parts. By embedding such a tool into their planning process, NACO can have a more integrated design approach for the landside and also automate repetitive tasks. This can lead to more flexible solutions that adapt better to potential future changes. While the outcome still depends on factors such as flight schedules, a data-driven parametric approach allows exploring a wider range of design alternatives than static rules of thumb. Unlike rules of thumb, which are safe and conservative, this approach is robust because it can adapt to changing conditions.

For the suggested parametric tool, the division between designer input and what is created and added by the computer is critical. The designer defines objectives, constraints, key performance indicators and the relationships between landside parameters. This determines the conceptual boundaries of the design space. Once this framework has been created, a parametric model can quickly produce and evaluate alternative landside layouts, helping with the time-consuming test of manually testing and drawing all the different iterations. The designer then comes back to interpret the results created by the parametric model. The designer then fine-tunes the parameters to ensure that the automation enhances the design process.

3.4. Literature on Parametric Design

Parametric and generative design tools have gained popularity in architecture, engineering, and urban design because they help designers explore large solution spaces efficiently. Grasshopper, a visual programming environment for Rhinoceros 3D, provides a possibility to link design parameters to geometric outcomes. When combined with optimisation plug-ins such as Galapagos, these tools can be used to search for optimal design configurations based on multiple performance criteria. This approach supports more informed and adaptive decision-making in early design stages. Table 3.2 presents an overview of relevant literature on parametric and optimisation tools for design exploration.

Table 3.2: Relevant literature on parametric and optimisation tools for design exploration

Author(s)	Year	Context / Tool	Key Findings / Relevance
Caldas, L.	2008	Architectural optimisation using genetic algorithms	Introduced early methods for performance-driven design, forming a basis for the later use of evolutionary solvers such as Galapagos.
Turrin, M., von Buelow, P., & Stouffs, R.	2011	Rhino/Grasshopper generative framework	Showed multi-objective optimisation of complex architectural geometries, relevant for adaptive spatial layouts.
Janssen, P., & Stouffs, R.	2015	Parametric design (Grasshopper)	Linked parametric modelling to performance evaluation, showing how geometries can be optimised based on design criteria.
Weber, R., Mueller, C., & Reinhart, D.	2022	Generative design of floor plans	Used automated layout generation for efficiency and adaptability, might be applicable to airport landside geometry exploration.

Several studies have showed the potential of parametric and generative design methods in solving complex spatial design problems. For example, a framework combining parametric modelling and genetic algorithms has been used in architectural form optimisation while adhering different constraints (Turrin et al., 2011). A taxonomy of parametric modelling methods was created to connect geometric modelling with iterative evaluations of performance (Janssen and Stouffs, 2015). Generative optimisation methods have also been used for generating building layouts and for floor plan optimisation, proving the increase in efficiency and adaptability (Weber et al., 2022). Furthermore, evolution based generative design methods have showed how genetic algorithms can search multi-criteria design spaces to optimise architectural forms (Caldas, 2008). These different applications show that parametric optimisation methods can link parameters with geometries and simulation, this could be also tested in airport landside planning, where design decisions must balance accessibility, capacity and operational performance.

These applications show that parametric optimisation can help speed up the design process by automating repetitive tasks and by helping the designer to test many configurations under different scenarios. This approach might be used in the airport landside context, where design decisions must balance accessibility, capacity, and operational performance. Using a tool like Grasshopper for landside planning could help planners to dynamically explore the effects of design parameters on key performance indicators. Solvers such as Galapagos, which use optimisation algorithms to automatically search for the best-performing design options, can identify trade-offs between the competing objectives.

Although Grasshopper and Galapagos have been widely adopted for building and urban design, they are not yet common in the airport planning context. A likely explanation is that airport projects involve higher complexity, stricter operational and regulatory requirements, and more uncertainty in early-phase data. These factors may make it more difficult to use parametric tools in the same way as they are used in building or urban projects. In addition, the airport industry has traditionally relied on conservative, rule-based methods. As a result, parametric approaches have not yet been fully adopted, but precisely these characteristics suggest a strong potential for data-driven tools to support more dynamic and adaptable decision-making.

3.5. Literature on Passenger Experience

While the architectural design of the airport is critical and must be efficient, the passenger experience is still the most important factor affecting the total terminal performance. The design of the landside structures, including access roads, kerbs, parking, and public transport stations, directly influences perceived level of service. Literature on passenger experience focuses both on quantitative factors such as Level of Service, walking distance, processing time and on qualitative factors such as comfort, readability, and convenience. Table 3.3 presents an overview of relevant literature on passenger experience and performance indicators.

Table 3.3: Relevant literature on passenger experience and performance indicators

Author(s)	Year	Focus	Key Findings / Relevance
IATA	2022	Level of Service framework	Defines quantitative standards for space and comfort; provides benchmark for passenger-related performance metrics.
Bandara, Wirasinghe & de Barros	1992	Terminal configuration and walking distances	Demonstrated that pier/satellite layout, gate distribution, and processing area locations significantly affect passenger walking distances; emphasised need for efficient circulation planning
Daamen, Hoogendoorn & Bovy	2005	Route choice and level changes	Found that passengers avoid level changes when possible; ramps and escalators increase route attractiveness compared to stairs.
Braaksma & Cook	1977	Gate scheduling and walking distance reduction	Showed that optimised gate assignment can reduce total walking distance; highlighted importance of spatial and operational coordination.
de Neufville & Odoni	2003	Passenger flow and terminal system modelling	Developed system-level models integrating gate positioning, transfer flows, and passenger behaviour; foundational reference for terminal optimisation.
Popovic, Kraal & Kirk	2010	Passenger experience and spatial design	Highlights the interdependence of passenger activities, spatial layout, and emotional experience; supports holistic design approach minimising walking and level changes.

One of the most often used standards for designing or evaluating the passenger satisfaction within terminals is the LoS (Level of Service) Concept, which was first introduced in IATA's Airport Development Reference Manual (ADRM). For decades, the ADRM has developed airport industry guidelines and resources related to airport planning, capacity, and design. Before, the LoS concept consisted of six different levels categorising facilities from "A" (excellent) to "F" (unacceptable) based on spatial and operational factors. The current framework categorises each facility into four service categories: under-provided, sub-optimum, optimum, and over-design (International Air Transport Association, 2022). This is based on spatial and temporal indicators such as space per passenger, waiting and queue times, and seating/standing availability (see Figure 3.1). This shift was made because planning for maximum comfort levels frequently resulted in over-dimensioned and cost-inefficient facilities. Right now, with the new framework, "optimum" LoS provides the best balance between passenger comfort, operational performance, and economic feasibility.

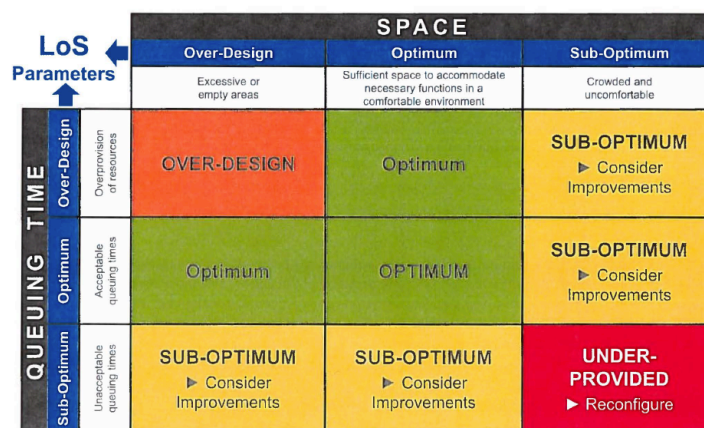


Figure 3.1: LoS Space-Time Diagram (International Air Transport Association, 2022)

Having said that, LoS alone is insufficient for capturing the full passenger experience. The Airport Development Reference Manual (ADRM) also mentions other important factors to consider. "The best airport terminals are those that provide the most clear and direct path across all passenger and public journey paths (domestic, international, and transfer traffic)" (International Air Transport Association, 2022). Intuitive wayfinding and passenger orientation are two important factors. To this, there are a lot of architectural considerations that should be taken into account, like the use of certain materials, lighting, outdoor views and other physical directional clues. This enhances passenger orientation and is much more effective than relying on signage. A transparent building philosophy can be used to enhance the passenger orientation at an airport. The most simple way for passengers to orientate is allowing them to see their final destination.

However, the architectural considerations are sometimes difficult to quantify and at another level of detail, considering the master planning level this research looks at. The Airport Development Reference Manual (ADRM) (International Air Transport Association, 2022) also gives recommendations for factors that are more at level of detail of master planning level and that are easier to quantify, those are:

- **Minimise walking distances**

Walking distances should be minimised for all passenger journeys. Making the passenger route from and to the aircraft as simple as possible will help to reduce the walking distance. Bigger walking distances can be accepted if a form of mechanical assistance is available to the passengers.

- **Minimise level changes**

Level changes for passengers should be minimised in all terminal designs. Departure and arrivals flows can be on different levels, but level changes within the same passenger journey should be minimised. Minimising level changes can lead to an increase in the footprint of the building, and therefore walking distance, so a right balance should be found.

- **Minimise conflict points**

Conflict points should be minimised with busy roads at the landside. At shared space places where the vehicles have a low speed, such as the car parking and the kerbs, pedestrian crossings can exist. These pedestrian crossings should be as short as possible to reduce the interaction. Minimising conflict points can lead to an increase in level changes, so this trade-off should be considered.

- **Separation of passenger flows**

Passenger flows should be minimised, this should be for international/domestic flows but especially for arriving/departing flows. Separating the arriving/departing flows can be done by creating two levels above each other. This separation will result in a segregated kerb and will lead to more level changes, but less conflict points.

Other researches also show that walking distance and level changes have a substantial impact on airport passenger experience, with impact on route selection and terminal design. Research shows that walking distance is an important factor in airport terminal configuration (Bandara and Wirasinghe, 1992). Level changes significantly influence the route choices of passengers, with different bridging methods (ramps, stairs, escalators) having varying impacts on route attractiveness (Daamen et al., 2005).

Additional research shows that walking distances can be reduced through proper gate scheduling when designing the terminal (Braaksma, 1977). Researchers have developed complex models to optimise passenger movement, taking into account factors like transfer passengers and gate positioning (De Neufville et al., 2002). More recent research (Popovic et al., 2010) highlights the interdependence of passenger activities and experiences, highlighting the need for integrated airport design that minimises walking distances and simplifies level changes.

To be able to quantify passenger experience in the design context, studies often translate comfort and accessibility into spatial indicators. For example, this can be done by linking walking distances, level changes, space per passenger, waiting and queue times, and seating/standing availability to user satisfaction ratings. These insights can help with the development of a parametric model where passenger experience is included as an explicit optimisation objective.

Integrating passenger experience into the design process will for this research be limited to walking distances. Because the parametric model will only consider a 2D situation, it is difficult to include the other components (level changes, conflict points, and flow separations) in the optimisation. Adding these components would require a model formulation that could handle a 3D situation, which would further complicate the optimisation. With the limited time for this research, this was not considered feasible. Besides that, walking distance is easy to quantify, and there is little ambiguity about it. If the other components were to be included, the problem would change to a multi-objective optimisation problem, where certain weights would have to be assigned to the different components. Section 4.6 further explains how walking distances are implemented in the parametric model.

3.6. Summary

This chapter provides the theoretical foundation for the development of the parametric model by reviewing different literature on airport landside planning, parametric design, and passenger experience. This chapter first explains the search strategy used to identify relevant literature, outlining the concept groups, keywords, and selection criteria that guided the review. This structured approach makes sure that the literature included in this chapter is both scientifically solid and aligned with the scope of this research.

The literature overview highlights how airport landside planning is traditionally based on passenger forecasts and rule-of-thumb approaches, which often limit adaptability and lead to inefficiencies in the early phase design process. It also shows that public transport integration is increasingly being seen as a crucial component for improving airport connectivity, but that it remains insufficiently incorporated in existing design processes. The literature review further identifies the decision support tools that exist in other fields, but that there currently is no comprehensive tool that provides an integrated, data-driven tool for the entire landside system. This reveals a knowledge gap that can be addressed by a parametric design approach, which can enable rapid scenario testing and more flexible spatial exploration.

The chapter then further looks into parametric and generative design literature, showing how these methods are widely applied in architecture and urban planning to automate design tasks and evaluate large solution spaces. Tools such as Grasshopper and optimisation algorithms like Galapagos have been proven to support iterative and performance-driven design, although their use in airport planning remains limited. The literature on passenger experience underlines the importance of walking distances, level changes, conflict points, and passenger flow separation. Both IATA standards and other relevant studies are used to identify quantifiable indicators relevant for landside design.

Overall, this chapter provides the academic basis for developing a parametric decision support tool. It outlines the current limitations of airport landside planning and highlights the potential of parametric design methods. The chapter also shows how passenger experience can be translated into measurable performance indicators. This literature study provides insights into the essential factors, assumptions, and objectives that will be used for the creation of the parametric model in the next chapters.

4

System Analysis Airport Landside

4.1. Introduction

The landside of an airport passenger terminal is a complex and interdependent system, acting as a critical interface between the ground transportation networks and the terminal building. It involves all the infrastructure and services located between the airport boundary and the terminal interface, including access roads, kerbside, parking, and public transport facilities. As passenger volumes grow and the modal split changes, the efficiency and adaptability of the landside system become increasingly important to guarantee seamless connectivity, reduce congestion, and enhance the overall passenger experience.

This chapter presents a system analysis of the airport landside, providing a detailed overview of the landside structures, demand groups, system constraints and interactions. The goal is to understand how each component is integrated into the landside and how each individual landside structure is sized. It is also important to know the spatial relationships between the different landside structures and how they influence each other's location and configuration. Another important part is to define the key parameters and performance indicators for use in the parametric model.

This chapter is structured as follows: Section 4.2 presents an overview of the airport landside system, stating which components of the landside fall within the scope of this research. Section 4.3 describes the demand, presenting the different demand groups, peak hour demand, and modal split. Section 4.4 examines the main landside structures. Section 4.5 discusses the constraints and interactions that shape the airport landside. Section 4.6 explains how passenger experience is used in modelling and evaluating the different design scenarios. The chapter wraps up with a summary, linking these system elements to the development of the parametric model.

4.2. Overview of Airport Landside Systems

Airports can be divided into a landside and an airside. The definition given by Janić, 2018 for the distinction between the airside and landside is as follows: "The airport airside area consists of terminal airspace, runways and taxiways, and apron/gate complex, all intended to handle aircraft of different size (seating capacity) operated by different airlines. The landside area consists of air passenger and freight/cargo terminal(s), technical complex, and landside access modes and their systems." Not everything concerning the airport is of importance for this research, but it is useful to have an understanding of the whole system. Figure 4.1 shows a simplified scheme of an airport, indicating the different components that belong to the airside and landside. The terminal building is the actual interface between the landside and the airside, which also forms the separation between the restricted area and the open access area of the airport.

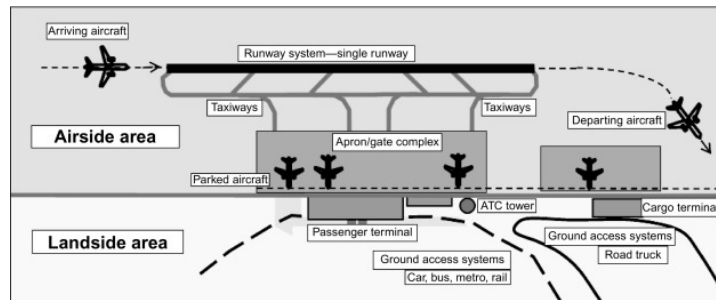


Figure 4.1: Simplified scheme of an airport components showing the landside and airside (Teodorović and Janić, 2017)

As already mentioned in section 1.4 this research only focusses on certain parts of the landside, which is the infrastructure in front of the passenger terminal. While the airside is outside the scope of this research, it still influences the shape and boundaries of the landside, for example through the runway configuration and its spatial constraints. The internal terminal components, such as check-in, security, and baggage claim, are also outside the scope of this research, as well as the design of the stand-alone public transport stations. Figure 4.2 shows a simplified landside, not all components shown in this Figure are relevant for this research. Only the landside structures in front of the passenger terminal will be taken into account, these are the terminal area roadways and the structures inside of these roadways. So landside structures like the cargo terminals, long-term parking and other remote locations are outside the scope of this research. The terminal configuration and whether there is a central or decentralised layout with one or more headhouses should also be considered, because this may also influence the landside structures. The landside structures that will be discussed in the next section are: terminal area roadways, kerbside, parking, car rental facilities, and public transport facilities.

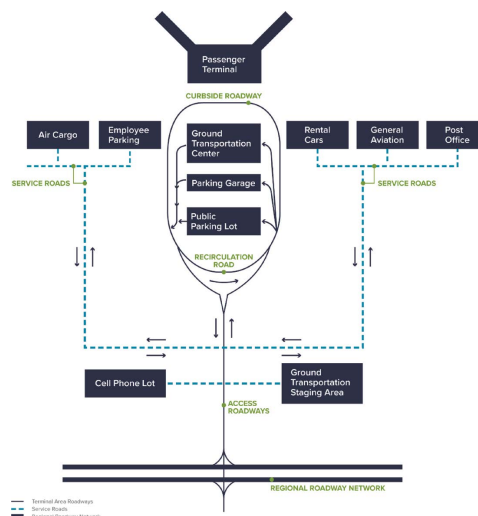


Figure 4.2: Airport landside showing the landside structures and road types (Board et al., 2024)

4.3. Demand

There are distinct demand groups contributing to the total demand for the landside infrastructure of the airport. Besides the different demand groups that shape the landside, the modal split provides an insight on how this total demand is divided over the different access modes. By adding a temporal aspect it is possible to better predict how much capacity is needed for the various components of the landside during the peak hour.

4.3.1. Demand Groups

While the passengers make up the biggest portion of the total demand, landside infrastructure must also accommodate airport employee, commercial employee, and visitor/delivery/maintenance demand. Within distinct demand groups, even a more detailed sub-division can be made which will be specified in the following sections.

The formulas used in this section were based on an internal Excel file provided by NACO (NACO, 2022), which is used within the company to assess terminal landside requirements based on forecast data. The provided ranges in this section partly come from the same Excel file (NACO, 2022) as the formulas, but also from another internal Excel file provided by NACO (NACO, 2025) which contains airport benchmarks.

Passengers

The largest and most variable demand group for the airport landside systems are formed by the passengers. They can be categorized into:

- **Origin/Destination (O/D) Passengers:** start or end their journey at the airport
- **Transfer Passengers:** only transfer at the airport, generally generate no direct demand for the landside facilities

Important inputs to calculate the passenger demand influencing the landside systems are the "MAP" (Million Annual Passengers), the "transfer percentage" and the "landside reporting factor". The MAP is usually derived from strategic demand forecasts based on historical passenger volumes and economic growth indicators. MAP forecasts are used to develop a Design Day Flight Schedule (DDFS), this is done so that annual passenger demand can be translated into operational design inputs.

The transfer percentage depends on the type of airport. Although the IATA ADRM stresses the importance of transfer passenger segmentation, it does not provide explicit transfer percentages for reference. Therefore, transfer percentages are estimated based on benchmark data from similar airports. Point-to-point airports typically have a lower transfer percentage of around 0-10% and hub airports typically have a higher transfer percentage of around 30-60% depending on the kind of hub. By subtracting the transfer passengers from the MAP, the annual O/D passenger throughput can be calculated. In order to estimate the passenger demand influencing the landside systems, the annual O/D passenger throughput needs to be multiplied by a landside reporting factor. In section 4.3.2 this number will be used in further calculations to come to a peak hour demand. The landside reporting factor is how many people arrive on the landside within the same hour, and is typically around 80-90%. It is used to calculate the landside peak hour demand based on the airside peak hour demand.

To estimate the Landside Passenger Demand, equation 4.1 is used:

$$\text{Landside Passenger Demand} = \text{MAP} \times (100\% - \text{Transfer Percentage}) \times \text{Landside Reporting Factor} \quad (4.1)$$

Employees

The second largest demand group for the airport landside systems are formed by the employees. They can be categorized into:

- **Airport Employees:** employed directly by airport-related operations and aviation services
- **Commercial Employees:** employed in non-aviation commercial activities located on or near the airport premises

Important inputs to calculate the airport employee demand are the "MAP" (Million Annual Passengers) and the number of "Airport Employees per MAP". The "Airport Employees per MAP" is a planning parameter and is different for every airport, it typically lies within the range 500-1500 but there can be some outliers for certain special airport cases. In section 4.3.2 this number will be used in further calculations to come to a peak hour number.

To estimate the Airport Employee Demand, equation 4.2 is used:

$$\text{Airport Employee Demand} = \text{MAP} \times \text{Airport Employees per MAP} \quad (4.2)$$

Important inputs to calculate the commercial employee demand are the forecast output "Total Annual Aircraft Movements", the planning parameter "Ratio Office Space per Movement" and the planning parameter "Space per Commercial Employee [sqm]". The last two parameters can be played with in the planning phase. In section 4.3.2 this number will be used in further calculations to come to a peak hour number.

To estimate the Commercial Employee Demand, equation 4.3 is used:

$$\text{Commercial Employee Demand} = \frac{\text{Total Annual Aircraft Movements} \times \text{Ratio Office Space per Movement}}{\text{Space per Commercial Employee (sqm)}} \quad (4.3)$$

VDM & Cargo

The last demand groups that can be specified are the VDM (Visitors Delivery Maintenance) and cargo, for both groups demand is typically more spread out across the day. The VDM demand is based on the number of airport employees, a ratio of approximately 15% has been estimated for this.

To estimate the VDM Demand influencing the landside systems, equation 4.4 is used:

$$\text{VDM Demand} = \text{Total Airport Employees} \times \text{Ratio VDM per Airport Employee} \quad (4.4)$$

The demand that is generated by the cargo facilities is based on O&D cargo tonnage, this is left out of scope for this research. This can be done because the share of cargo is usually small, and when the share of cargo is large, there is often dedicated infrastructure to access the cargo facilities.

4.3.2. Peak Demand

For airport planners, it is essential to size the landside systems based on a defined peak demand, rather than simply designing for the busiest day of the year. Using the busiest day as the design principle would result in a significant overcapacity for the rest of the year, while designing for the average demand would result in frequent under capacity during the busy periods. In practice, landside planning relies on a peak period that may be exceeded only an acceptable amount of the times, providing a right balance between costs and the required capacity to meet the peak demand. The passenger demand, the airport employee demand and the commercial employee demand each has its own way of being calculated. The passenger demand and airport employee demand depend on the annual passenger throughput, and the commercial employee demand depends on the annual aircraft movements.

The formulas used in this section were based on an internal Excel file provided by NACO (NACO, 2022), which is used within the company to assess terminal landside requirements based on forecast data. The provided ranges in this section partly come from the same Excel file (NACO, 2022) as the formulas, but also from another internal Excel file provided by NACO (NACO, 2025) which contains airport benchmarks. A more detailed explanation is provided in the following subsections.

Passengers

Daily demand profiles for passengers can be used to identify peak periods for arrivals and departures, which influence the required landside capacity. These demand profiles typically show one or more peaks depending on the airport typology and flight schedule structure. Uncongested airports typically have sharp demand peaks over the day. As the demand grows, relatively more demand occurs during the non-peak hours filling up the "valleys" in the demand profile. Saturated airports generally have their demand more evenly distributed across the operational hours.

In early-phase planning, passenger demand is often estimated by using the DPD (Design Peak Day) and the DPH (Design Peak Hour). There are many definitions in use for the DPD and DPH, but in practice it makes little difference which alternative is used as long as it satisfies the following condition: "The DPD and DPH should not be the day or hour, of the year with the highest traffic demand but one with a demand that is exceeded only on a reasonably small number of instances during the year" (De Neufville et al., 2013). In early-phase planning, demand is often estimated using the 30th busiest hour of the year (also known as the 30th peak hour) as a design reference.

The airport planners at NACO get a forecast from the forecast team containing data on the annual passenger throughput and the annual aircraft movements, based on these numbers the 30th peak hour can be calculated. Getting all this data for an airport can be an extensive task. Besides that, the data is often also confidential and therefore this data cannot simply be used. Fortunately, there is also a way to approximate peak hours by using rules of thumb that are sufficiently accurate for early-phase planning. Depending on the total annual passengers, a conversion coefficient can be selected, see Table 4.1.

Table 4.1: Conversion coefficients for estimating number of DPH passengers from annual figures (De Neufville et al., 2013)

Total Annual Passengers (millions)	DPH Passengers as % of Total Annual Passengers
20 <	0.03
10 - 20	0.035
1 - 10	0.04
0.5 - 1	0.05

For the peak hour, passenger demand can be assessed using the 2-way PH passengers or by separately evaluating the 1-way PH arrival passengers and 1-way PH departure passengers. The choice depends on the layout of the kerb. In the case of a combined kerb, the 2-way PH passengers should be considered. If the kerb is segregated, the 1-way PH arrival passengers and 1-way PH departure passengers should be considered separately. The 2-way PH passengers can be estimated by multiplying landside passenger demand (from equation 4.1) by a peak hour conversion coefficient.

To estimate the 2-Way PH Passengers for the landside, equation 4.5 is used:

$$\text{2-Way PH Passengers} = \text{Landside Passenger Demand} \times \text{Conversion Coefficient PH} \quad (4.5)$$

The 1-way PH departure passengers and the 1-way PH arrival passengers can be estimated by multiplying the 2-way PH passengers (from equation 4.5) by a conversion coefficient. For departures this percentage typically lies around 55-70% and for arrivals this percentage is typically a bit higher.

To estimate the 1-Way PH Departure Passengers for the landside, equation 4.6 is used:

$$\text{1-Way PH Departure Passengers} = \text{2-Way PH Passengers} \times \text{Conversion Coefficient Departure} \quad (4.6)$$

To estimate the 1-Way PH Arrival Passengers for the landside, equation 4.7 is used:

$$\text{1-Way PH Arrival Passengers} = \text{2-Way PH Passengers} \times \text{Conversion Coefficient Arrival} \quad (4.7)$$

Airport Employees

As a first step, the number of airport employees present during the peak period must be calculated. A day can be divided into three periods of eight hours each. Approximately 50% of the total airport employee demand (from equation 4.2) is present in the peak period. In the peak hour, approximately 50% of the total number of airport employees in the peak period is present.

To estimate the PH Airport Employees, equation 4.8 is used:

$$\text{PH Airport Employees} = \text{Airport Employee Demand} \times \text{Percentage in Peak Period} \times \text{Percentage in PH} \quad (4.8)$$

Commercial Employees

For the commercial employees the calculation is similar, only the percentages are different. First, the number of commercial employees present during the peak period must be calculated. A day is again divided into three periods of eight hours each, but here the distribution of employees during the day is even more skewed. Approximately 90% of the total commercial employee demand (from equation 4.3) is present in the peak period. In the peak hour, approximately 33% of the total number of commercial employees in the peak period is present.

To estimate total PH Commercial Employees, equation 4.9 is used:

$$\text{PH Commercial Employees} = \text{Commercial Employee Demand} \times \text{Percentage in Peak Period} \times \text{Percentage in PH} \quad (4.9)$$

4.3.3. Modal Split

The modal split describes how passengers, employees, and other users, access and exit the airport through different modes of transport. This is a significant part in estimating the landside infrastructure demand, influencing the required capacity for the kerbside, parking facilities, car rental facilities, and the public transport facilities. Making an accurate estimate of the modal split and understanding its implications is essential for making well-informed decisions about the transport integration and space allocation.

The formulas used in this section were based on an internal Excel file provided by NACO (NACO, 2022), which is used within the company to assess terminal landside requirements based on forecast data. The provided ranges in this section partly come from the same Excel file (NACO, 2022) as the formulas, but also from another internal Excel file provided by NACO (NACO, 2025) which contains airport benchmarks.

The modal split is typically expressed as the percentage of passengers or employees using each mode. These modes include:

- public transport (rail, MRT, bus)
- touring car
- shuttle bus / mini bus
- taxi
- private car
- rental car

The PH demand for the different modes for the demand groups can be estimated by multiplying the total PH demand from the demand groups (from equation 4.5, 4.6, and 4.7) with the mode percentages.

To estimate the PH demand for the different modes for the demand groups, equations 4.10, 4.11 and 4.12 are used:

$$[\text{Mode}] \text{ PH Passengers} = [\text{2-Way or 1-Way}] \text{ PH Passengers} \times [\text{Mode}] \text{ Percentage} \quad (4.10)$$

$$[\text{Mode}] \text{ PH Airport Employees} = \text{PH Airport Employees} \times [\text{Mode}] \text{ Percentage} \quad (4.11)$$

$$[\text{Mode}] \text{ PH Commercial Employees} = \text{PH Commercial Employees} \times [\text{Mode}] \text{ Percentage} \quad (4.12)$$

After calculating the modal split, the total number of passengers or employees that make use of a specific mode in the peak hour is known. To translate these numbers into requirements for the landside systems, two additional components are needed: "occupancy" (number of passengers in a vehicle) and "PCE" (Passenger Car Equivalent). Occupancy indicates the number of airport users per vehicle and excludes accompanying persons who are not part of the airport demand (e.g., drivers or family members). This is needed to translate the peak hour demand to the number of vehicles in the peak hour per mode influencing the landside systems. The PCE expresses different vehicle types in a common unit, allowing to calculate the required number of lanes on access roads and kerb(s).

To estimate the Total Vehicles per mode influencing the landside systems, equation 4.13 is used:

$$[\text{Mode}] \text{ Total Vehicles} = \frac{[\text{Mode}] \text{ Total Passengers}}{[\text{Mode}] \text{ Occupancy}} \quad (4.13)$$

To estimate the Total PCE per mode influencing the landside systems, equation 4.14 is used:

$$[\text{Mode}] \text{ Total PCE} = [\text{Mode}] \text{ Total Vehicles} \times [\text{Mode}] \text{ PCE} \quad (4.14)$$

4.4. Physical Components

In this section there will be looked at the different physical components mentioned in section 4.2 in more detail. For each component it is important to find out how it is sized based on the predicted demand.

The formulas used in subsections 4.4.1 Terminal Area Roadways, 4.4.2 Kerbside, 4.4.3 Parking and 4.4.4 Car Rental Facilities were based on the internal Excel file provided by NACO (NACO, 2022), which is used within the company to assess terminal landside requirements based on forecast data. The formulas and values used in subsection 4.4.5 were obtained through discussions with Barth Donners, sustainable mobility consultant at NACO (personal communication, August 2025).

4.4.1. Terminal Area Roadways

The terminal area roadways consist of multiple important roads that can be seen in Figure 4.2, these are the access road, the kerbside road and the recirculation road. One other road that is not explicitly indicated in Figure 4.2, but that is important to size, is the passenger area access road which forms a circle and connects all other roads. The kerbside road is discussed separately in the next section. Below, an explanation is given on how the airport access road, passenger area access road, and recirculation road are sized.

The airport access road and passenger area access road are sized using the same method. First, the PCE values from the different modes (from equation 4.14) are summed for each demand group defined in section 4.3. Next, these totals should be multiplied by the share of PAX PH per demand group.

To estimate the Total PCE per demand group, equation 4.15 is used:

$$[\text{Demand Group}] \text{ Total PCE} = [\text{Demand Group}] \text{ Vehicles (PCE)} \times [\text{Demand Group}] \text{ Share of PAX PH} \quad (4.15)$$

The resulting PCE values are then added across all demand groups to get the total PCE needed for 2 directions, dividing this by 2 gives the total PCE needed for 1 direction.

Once the Total PCE for 1 direction is known, the lane requirement per direction can be calculated. This is done by dividing the total Vehicles (PCE) in 1 direction by the road capacity (PCE/hour/lane) which depends on the speed (km/h) and Level of Service (LoS) (A-F). For the airport access road a speed of 60 km/h and a LoS C is used and for the passenger area access road a speed of 40 km/h and a LoS C is used. The corresponding road capacity can be found in the ACRP report 266 (Board et al., 2024). The number of lanes must be rounded up to the next whole number, with a minimum of 2 lanes per direction to ensure redundancy.

To estimate the Lane Requirement per Direction, equation 4.16 is used:

$$\text{Lane Requirement per Direction} = \frac{\text{Total PCE 1 direction}}{\text{Road Capacity (PCE/hour/lane)}} \quad (4.16)$$

The recirculation road does not get sized, also for this road holds that there should be at least 2 lanes per direction for redundancy. And because the road is only used for recirculation, 2 lanes provide more than enough capacity.

4.4.2. Kerbside

In general, the kerbside is organised on one level as a combined kerb, where arriving and departing passengers share the same forecourt. However, when the space in front of the terminal is limited or passenger volumes become too high, airports often separate the flows over two levels. This results in a segregated kerb with dedicated arrival and departure kerbs on different levels. This vertical separation increases capacity and reduces conflicts between the two flows.

The calculation that need to be made to calculate the length of the kerb, is similar for the segregated kerb and the combined kerb. The most important difference is that for the segregated kerb two calculations need to be made, because the arriving and departing passengers each have there own kerb. For the segregated kerb the 1-way departure passenger peak and the 1-way arrival passenger peak is needed and for the combined kerb the 2-way peak is needed.

Kerb Length

The first step to calculate the needed kerb length is to determine which modes make use of the kerb, these are: touring car, shuttle bus / mini bus, taxi and private car. For every mode the distribution needs to be decided, for the touring car, shuttle bus / mini bus and taxi, this is always 100% and for the private car it is typically around 30%. The PH flow can be calculated by multiplying the total vehicles per mode (from 4.13) with the distribution.

To estimate the PH Flow per mode, equation 4.17 is used:

$$[\text{Mode}] \text{ PH Flow} = [\text{Mode}] \text{ Total Vehicles} \times [\text{Mode}] \text{ Distribution} \quad (4.17)$$

After calculating the peak hour flow per mode, the peak minute flow per mode can be calculated. The hourly flow (from 4.17) is converted into a flow per dwell time interval. The exponent -0.5 reflects the inverse square root relationship between flow and variability, while the constant 1.645 corresponds to the 95th percentile of the standard normal distribution. This calculation ensures that the design accounts for stochastic peaks.

To estimate the Peak Minute Flow per mode, equation 4.18 is used:

$$[\text{Mode}] \text{ Peak Minute Flow} = 1 + 1,645 \times \left(\frac{[\text{Mode}] \text{ PH Flow}}{60 / [\text{Mode}] \text{ Kerb Dwell Time}} \right)^{-0.5} \quad (4.18)$$

After calculating the peak minute flow per mode, the vehicle flow per mode can be calculated. The vehicle flow per mode represents the number of vehicles that are expected to be on the kerb at the same time. The PH flow follows from 4.17 and the peak minute flow follows from 4.18.

To estimate the Vehicle Flow per mode, equation 4.19 is used:

$$[\text{Mode}] \text{ Vehicle Flow} = \left(\frac{[\text{Mode}] \text{ PH Flow}}{60 / [\text{Mode}] \text{ Kerb Dwell Time}} \right) \times [\text{Mode}] \text{ Peak Minute Flow} \quad (4.19)$$

To get from the vehicle flow per mode (from 4.19) to the needed kerb length per mode, the vehicle flow per mode should be multiplied by the bay length of every mode. To get the total kerb length needed, the kerb lengths per mode should be added to each other.

To estimate the Kerb Length per mode, equation 4.20 is used:

$$[\text{Mode}] \text{ Kerb Length} = [\text{Mode}] \text{ Vehicle Flow} \times [\text{Mode}] \text{ Bay Length} \quad (4.20)$$

Kerb Lanes

Besides calculating the kerb length, the number of lanes needed to accommodate the total vehicle flow at the kerb should be calculated. To do this, the total vehicle flow (from 4.19) at the kerb should be divided by the road capacity (PCE/hour/lane) which depends on the speed (km/h) and Level of Service (LoS) (A-F). For the kerb road a speed of 40 km/h and a LoS C is used. The corresponding road capacity can be found in the ACRP report 266 (Board et al., 2024). The number of lanes must be rounded up to the next whole number, with a minimum of 2 lanes per direction to ensure redundancy.

To estimate the Kerb Lane Requirements, equation 4.21 is used:

$$\text{Kerb Lane Requirements} = \frac{\text{Total Vehicle Flow}}{\text{Road Capacity (PCE/hour/lane)}} \quad (4.21)$$

Kerb Layout

Once the required kerb length and number of lanes are known, the next step is to determine the forecourt layout, which influences the overall width of the kerb. Several layout options exist, these can be found in the Airport Development Reference Manual from IATA (International Air Transport Association, 2022). The most simple layout, a single forecourt layout, is shown in Figure 4.3. This layout consists of one parking lane, one manoeuvre lane at a number of through lanes depending on demand. The kerb length should be visually relevant to the terminal building. If more kerb length is needed or if the landside length is too small, it is possible to create a multiple forecourt layout where single forecourt layouts are placed in parallel.

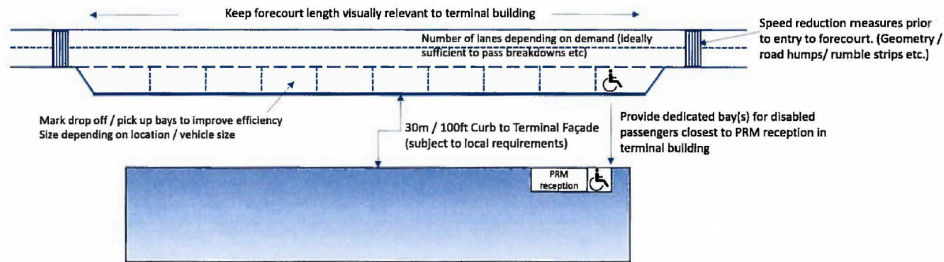


Figure 4.3: Simple departure kerb and forecourt layout (International Air Transport Association, 2022)

4.4.3. Parking

To calculate the required square meters needed for passenger car parking, the first step is to calculate the required number of parking bays. This is done by dividing the annual O/D passenger throughput (from 4.1) by the ratio bays per MAP.

To estimate the required number of Passenger Parking Bays, equation 4.22 is used:

$$\text{Passenger Parking Bays} = \frac{\text{Annual O/D Passenger Throughput (MAP)}}{\text{Ratio Passenger Parking Bays per MAP}} \quad (4.22)$$

To get the required square meters for passenger parking, the required number of passenger parking bays (from 4.22) should be multiplied by the area demanded per car parking bay.

To estimate the required Square Meters Parking, equation 4.23 is used:

$$\text{Square Meters Parking} = \text{Passenger Parking Bays} \times \text{Area Demanded per Bay} \quad (4.23)$$

4.4.4. Car Rental Facilities

Calculating the required square meters needed for car rental parking is similar to calculating the required square meters needed for passenger car parking. Again, the first step is to calculate the required number of parking bays. This is done by dividing the annual O/D passenger throughput (from 4.22) by the ratio bays per MAP. The ratio bays per MAP for car rental parking is only much lower compared to the ratio bays per MAP for the passenger car parking.

To estimate the required number of Car Rental Parking Bays, equation 4.24 is used:

$$\text{Car Rental Parking Bays} = \frac{\text{Annual O/D Passenger Throughput (MAP)}}{\text{Ratio Car Rental Parking Bays per MAP}} \quad (4.24)$$

To get the required square meters for car rental parking, the required number of car rental parking bays (from 4.24) should be multiplied by the area demanded per car rental parking bay.

To estimate the required square meters for car rental parking, equation 4.25 is used:

$$\text{Square Meters Car Rental} = \text{Car Rental Parking Bays} \times \text{Area Demanded per Bay} \quad (4.25)$$

4.4.5. Public Transport Facilities

For the public transport facilities it is more difficult to calculate the required square meters. Most of the times for rail and MRT stations it depends on the number of concourses that are needed and for bus stations the number of bays that are needed. This usually does not come directly from the demand, but comes from the client's requirements. However, it is possible to estimate how many square meters is needed per platform for rail and MRT or bay for bus. This can then be multiplied by the number of platforms or bays to get the total number of required square meters for a public transport station.

For this research, the size of a rail station and a MRT station will be determined by a hard input from the airport planner, based on the requirements from the client. This hard input specifies the desired number of platforms per mode. However, defining this number is not straightforward. The position of the airport within the wider public transport network influences the sizing of the station, as the station may serve not only air passengers but also other non-passenger travellers. If the airport is connected to multiple public transport lines, it may also function as a transfer point, increasing demand. Additional lines may require more platforms to allow simultaneous arrivals and avoid operational conflicts. Once the number of platforms is defined, the next step is to estimate the required station area for each mode.

Below, for the station of each mode, it will be described how an estimate is made of the required area. These numbers were (unless otherwise stated) obtained through discussions with Barth Donners, sustainable mobility consultant at NACO (B. Donners, personal communication, August 2025).

Rail

Two things need to be sized for a train station, the length and width of the station and the length and width of the concourse. Starting with the station, followed by the concourse. The most normative dimension is the station length, which is based on the usual maximum length of a train combination.

Station

- *Width*: $[\text{Number of Tracks}] \times (6 \text{ m (Track Width)} + 7,5 \text{ m (Platform Width)})$
- *Length*: 400 m (*fixed*) (European Union Agency for Railways (ERA), 2023)

Concourse

- *Width*: 25 m (*fixed*)
- *Length*: $\text{Station Width} + 2 \times \text{Concourse Width}$

An important addition to the above calculation: if the station is above ground, it occupies the width and length of the station on the landside. If the station is underground, it occupies the width and length of the concourse on the landside. However, it must be taken into account that above the part of the station which is located underground brings restrictions for what can be built.

MRT

The calculation for a MRT station is similar to that of the train station. Two things need to be sized for a MRT station, the length and width of the station and the length and width of the concourse. Starting with the station, followed by the concourse. The most normative dimension is the station length, which is based on the usual maximum length of a MRT combination.

Station

- *Width*: $[\text{Number of Tracks}] \times (6 \text{ m (Track Width)} + 5 \text{ m (Platform Width)})$
- *Length*: 120 m (*fixed*) (Inc., 2023)

Concourse

- *Width*: 15 m (*fixed*)
- *Length*: $\text{Station Width} + 2 \times \text{Concourse Width}$

An important addition to the above calculation. If the station is above ground, it occupies the width and length of the station on the landside. If the station is underground, it occupies the width and length of the concourse on the landside. However, it must be taken into account that above the part of the station which is located underground brings restrictions for what can be built.

Bus

To estimate the required number of bus bays, the total bus demand in the peak hour is first converted into the number of bus trips needed by dividing it by the average bus occupancy. Since each bus occupies a bay for a fixed dwell time, this determines how many buses one bay can handle per hour. The total number of bus bays needed can be calculated by dividing the required number of bus trips by the processing capacity.

The calculation is a simplified calculation solely based on the peak hour demand coming from the air passengers. The position of the airport within the wider public transport network influences the sizing of the station, as the station may serve not only air passengers but also other non-passenger travellers. If the airport is connected to multiple public transport lines, it may also function as a transfer point, increasing demand. Additional lines may require more bus bays to allow simultaneous arrivals and avoid operational conflicts.

To estimate the Bus Bays, equation 4.26 is used:

$$\text{Bus Bays} = \frac{\text{Total Bus Demand PH} \times \text{Dwell Time Bus}}{60 \times \text{Occupancy Bus}} \quad (4.26)$$

Two things need to be sized for a bus, the length and width of the bay and the length and width of the station. Starting with the bay, followed by the station.

Bay

- *Width*: 12 m (*fixed*)
- *Length*: $\text{Occupancy Bus} \times \text{LoS Space Standard} / \text{Bay Width}$

Station

- *Width*: $\text{Number of Bays in Width Direction} \times \text{Bay Width}$
- *Length*: $\text{Number of Bays in Length Direction} \times \text{Bay Length}$

4.5. System Constraints and Interactions

The development of the airport landside is not only shaped by the expected demand but also by a range of constraints and interactions. These constraints define the limits within which solutions must be developed, while interactions between different landside components influence the overall efficiency and robustness of the system. Understanding both aspects is essential for creating realistic and adaptable landside plans. These different constraints and interactions are described below.

Existing Structures:

- *Terminal*: the size and number of terminal buildings (also called headhouses) determine where passengers should go and ensure a certain distribution of the passengers
- *Runways*: runways can be parallel to the terminal or perpendicular to it, this influences the boundaries and shape of the landside
- *Roads*: there are certain main roads where the airport access roads should connect to
- *Public Transport Network*: depending on the location of the airport in the public transport network there can be a rail station and/or MRT station, depending on the situation, these stations can be below or above ground and they can be an intermediate station or end station
- *Built Environment*: the built environment around the airport reduces the space available on the landside

Airport Constraints:

- *Terminal Offset*: from the terminal interface to the kerb needs to be an offset of at least 30 meters for safety reasons
- *Under Terminal*: if rail or MRT is under the ground, the platforms can not be under the terminal building or airside because of emergency exits, for the tracks there is no restriction
- *Terminal Entrances*: the amount of entrances in the terminal interface can affect the physical distribution of passengers on the landside

4.6. Passenger Experience

Passenger experience is an important factor in the optimisation and evaluation of the airport landside. In this research, passenger experience is implemented into the parametric model primarily through walking distance, which serves as a key performance indicator. Other factors such as level changes and conflict points can also have an impact on the passenger experience, however these are not explicitly modelled in this study and are only mentioned for completeness.

4.6.1. Walking Distance

Walking distance is calculated from the midpoint of each landside structure (kerb, parking, bus station, MRT station, and rail station) to the relevant terminal entrance. The midpoint of a landside structure is used as a consistent geometric reference point for estimating walking distances and avoids assumptions about how passengers are distributed within each landside structure. The model takes into account the different demand groups (O/D passengers, transfer passengers, and employees), the transfer passengers do not make use of the landside structures, so only the O/D passenger and employee demand are combined to one demand flow for every landside structure.

The calculation process is as follows:

- **Option 1: Unbundled paths without a spine**

Walking distance is measured from the midpoint of each landside structure directly to all terminal entrances. This option does not bundle all walking paths from the different landside structures into a single main path, because in this option there is no spine. The walking path for one landside structure consists of multiple straight lines from the midpoint of a landside structure to all the different terminal entrances, this is shown in Figure 4.4a. The total length of these different paths for one landside structure is then divided by the number of terminal entrances to calculate an average walking distance for the structure. This option provides a more decentralised distribution of the walking paths. However, this option is conceptual and used solely for modelling purposes.

- **Option 2: Bundled paths via a spine**

Walking distance is measured from the midpoint of each landside structure to a central spine and then from the spine a perpendicular line that connects to the terminal. This option bundles all walking paths from the different landside structures into a single main path over the spine. The walking path for one landside structure consists of two parts: a horizontal segment from the midpoint of a landside structure to the spine and a perpendicular segment over the spine to the terminal entrance, this is shown in Figure 4.4b. This option provides a more centralised distribution of the walking paths and provides more realistic walking paths avoiding going through landside structures. For modelling this option is selected since it is a more precise representation of reality.

- **Kerb specific calculation**

For the kerb, walking distance is always measured to all terminal entrances, regardless of the existence of a spine. As kerb usage is assumed to be uniformly distributed. For each terminal entrance, a straight perpendicular line to the vertical midpoint of the kerb is used to represent the walking paths. The total length of these lines is divided by the number of terminal entrances to determine the average walking distance.

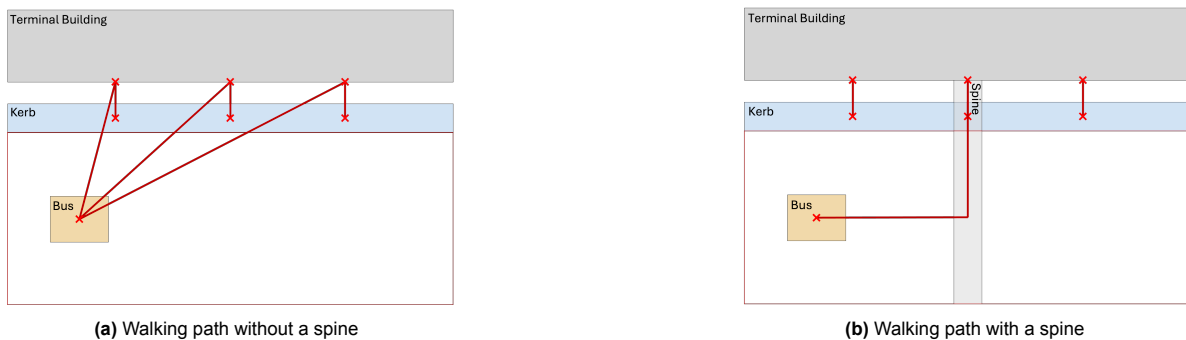


Figure 4.4: Comparison of walking path configurations: (a) without a spine, (b) with a spine, from the kerb/bus to the terminal

4.7. Summary

This chapter presents a system analysis of the airport landside, providing the foundation for the parametric model developed in the next chapter. It identifies the key components, demand groups, physical components, constraints, and performance indicators that influence landside planning. Internal NACO documents and expert input are used to define the parameters and relationships between the different landside structures.

The analysis includes the main landside structures in front of the terminal, such as the terminal area roadways, kerbside, parking, car rental facilities, and public transport stations. It explains how demand is derived for passengers and employees, and how peak hour flows and modal splits translate this demand into sizing requirements for the different landside structures. System constraints and spatial interactions are also taken into account, these determine the feasible design space and affect how passenger experience and the efficiency of the landside configuration can be balanced. Passenger experience is a crucial component in the system analysis and is used as a key performance indicator for the evaluation of landside configurations. The passenger experience is represented through the walking distance, which show the accessibility and convenience of the layout.

Overall, this chapter provides the foundation for the parametric model by defining the structure, demand groups, and performance indicators of the airport landside. It combines system constraints and passenger experience into one framework, allowing landside layouts to be evaluated in a consistent way. The insights from this chapter will be used for generating and testing different landside configurations in the next chapter.

5

Model Specification

5.1. Introduction

This chapter presents the model specification and is structured as follows: Section 5.2 describes the data requirements and data analysis tools. Section 5.3 describes the excel input and design input for the model. Section 5.4 explains the model structure and logic. Section 5.5 presents the model objective and scope. Section 5.6 provides an explanation on how the model optimisation works. This chapter wraps up with a summary, providing all the needed knowledge to understand the outcomes of the model in the next chapter.

5.2. Data Requirements and Data Analysis Tools

Data availability is a critical factor in the outcome of this research, especially considering the intended goal of developing a parametric model. The model needs real-world reference data to define the input parameters and compare design scenarios. This chapter describes the required data, sources for the data, and data processing and modelling tools.

5.2.1. Data Requirements

To support both the input and output of the parametric model, the following data is required:

- **Passenger Demand**
Includes the number origin/destination passengers, transfer passenger share, and peak-hour demand profiles based on flight schedules. This data is required to model the needed landside capacity and to model the landside configurations appropriately.
- **Employee & VDM Demand**
Besides the passengers arriving and departing from the airport, there are also employees working at the airport and VDM (Visitors Delivery Maintenance) that create demand that make use of the landside infrastructure. This should also be taken into account in order to have sufficient capacity.
- **Modal Split**
Modal split data (e.g., share of people arriving by car, taxi, public transport, etc.) is required for estimating vehicle flows, public transport usage, and kerbside demand.
- **Landside Infrastructure Dimensions**
Benchmark data from existing airports concerning kerb length, park capacity, road capacity, number of public transport platforms, and walking distances from the different landside structures to the terminal entrances.

The data mainly comes from internal NACO projects and internal benchmark Excels from NACO.

5.2.2. Tools and Platforms

The primary tools used in this project are:

- Excel to manually calculate the input for Grasshopper starting from the demand data
- Python to process the Excel data in Grasshopper to be able to use it
- Grasshopper to build a model that can generate and optimise the layout configurations
- Rhino to visualise the generated layout configurations from Grasshopper
- Python to process the outcomes of the solver in Grasshopper to be able to get the KPIs

The selection of the tools is partly based on compatibility with NACO workflows and the potential for future internal use, but also based on how familiar I am with the tools. The airport planners working at NACO work with Excel sheets to size the different landside structures, starting with a demand forecast that they get from the forecast team. Part of the airport architects at NACO work with Rhino and Grasshopper, so they know how to use these programs and how to interpret the results. The selected tools therefore provide flexibility and transparency while maintaining accessibility for everyone involved.

5.3. Model Excel Input and Design Input

The tool consists of two parts, an Excel file and a Grasshopper model, Figure 5.1 shows the connection between them. The light purple area shows what the parametric model encompasses. There are two moments that the user of the tool can change the design input. The first time is by changing the planning parameters in the Excel file, which influence the requirements that are input for the Grasshopper model. The second time is by changing the design parameters in the Grasshopper model, this can be done by using the provided number sliders and drop-down menus for the different clusters in Grasshopper.

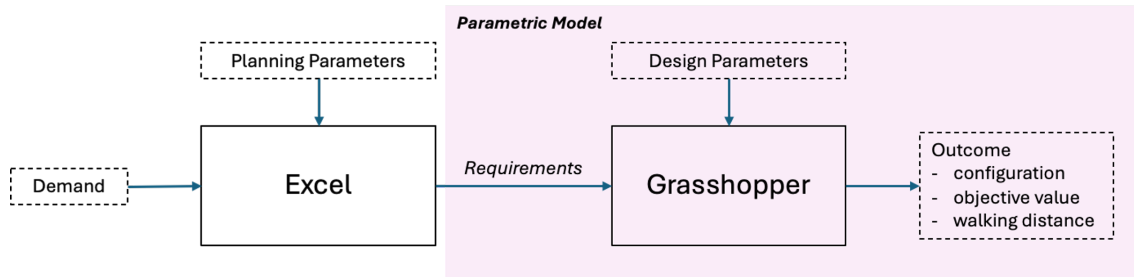


Figure 5.1: Connection Excel and Grasshopper showing the inputs, outputs and which part comprises the parametric model

The Grasshopper model fulfils three main functions, that can be seen as three steps that are performed one after the other. These three steps are shown in Figure 5.2. The first function of the Grasshopper model is the translation and visualisation of the input data. The demand data from Excel is processed and converted into geometries representing the landside structures, ensuring that the input is both interpretable and directly usable within the model. The second function is the optimisation of the spatial layout. In this step, the Grasshopper model determines the optimal locations of the landside structures using the built-in Galapagos solver, which evaluates many possible configurations while respecting the defined constraints. The third and final function of the Grasshopper model is the evaluation of the resulting layout. After an “optimal” landside configuration is found, the model calculates the relevant KPIs such as walking distances, allowing the performance of the generated layout to be assessed in a consistent and transparent way.

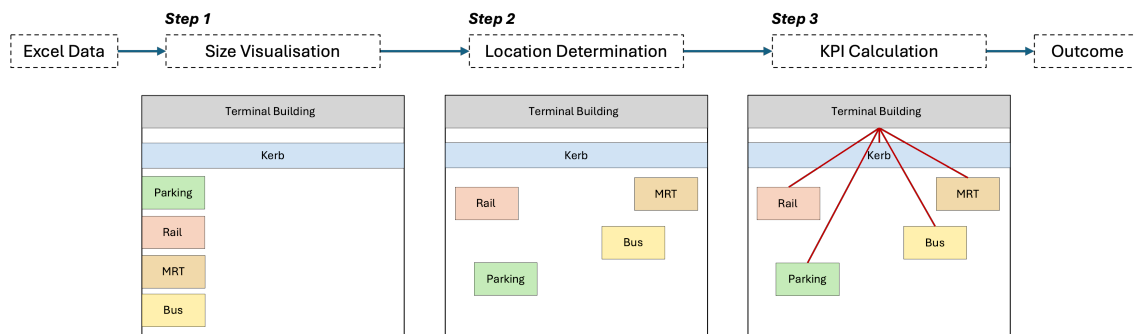


Figure 5.2: The three steps of the Grasshopper model

5.4. Model Structure and Logic

To build something in Grasshopper, "components" need to be placed on the Grasshopper canvas. These components need to be connected to each other through "wires", multiple connected components can form a "cluster" which can perform a certain task. It is up to the user of Grasshopper to create clear clusters to structure the model and create logic within it. An overview of the different Grasshopper clusters and the connections between them is showed in 5.4, the Figure has a directionality from left to right. Below Figure 5.4 an explanation is given of what happens in each cluster and what relationship it has with the other clusters. The green clusters indicates the input for the model, these create the landside structures and existing structures, together with the boundaries the passenger experience and location can be determined. All these clusters influence the orange clusters which are inputs for the solver. From the solver follow two outputs, a visual outcome and a numerical outcome.

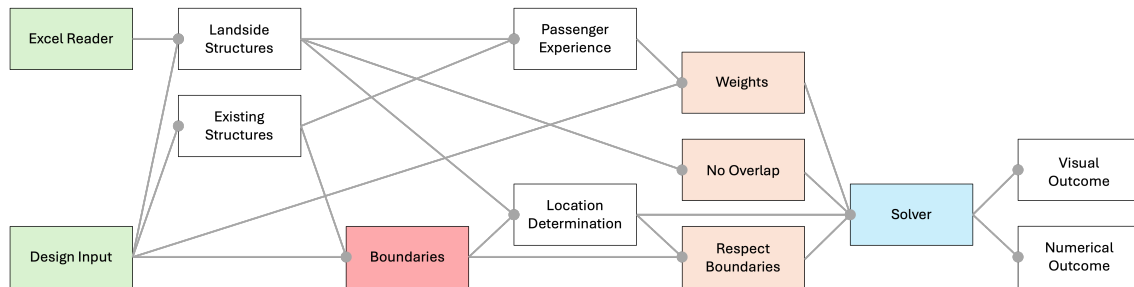


Figure 5.4: Overview of the Grasshopper clusters where the lines with dots show the connections and directionality

The model is divided in the following clusters:

- *Excel Reader:* This part uses a component with a small Python script to read the excel data and to translate it to useable inputs for the model.
- *Design Input:* This part consists of different sliders and drop-down menus where the user of the model can change the input parameters for the different landside structures.
- *Existing Structures:* The terminal building and landside boundaries need to be visualised by geometries to create the existing structures and boundaries where the other landside infrastructures need to interact with. Inputs for these existing structures come from the "Design Input" part.
- *Landside Structures:* The different landside structures need to be visualised by geometries, for every landside structure there is a separate cluster. Inputs for these landside structures come from the "Excel Reader" part and from the "Design Input" part.
- *Boundaries:* The different landside structures need to stay within certain boundaries of the landside and respect the location of the terminal, this cluster creates these boundaries. Inputs for these boundaries come from the "Design Input" part and from the "Existing Structures" part.
- *Location Determination:* For every landside structure there is a separate cluster that is responsible for determining the location of the landside structure within the boundaries. It can change the X-coordinate, Y-coordinate and the Rotation of the landside structures by using number sliders. These numbers sliders are connected to the solver which controls their values, and in that way also the location of the landside structures. Inputs for this location optimisation come from the "Landside Structures" part and from the "Boundaries" part.
- *Passenger Experience:* The passenger experience needs to be quantified, it consists of the walking distances. The walking distance can be determined by calculating the distance from the middle points of the landside structures to the terminal entrances. The walking paths can either be centralised, going through a spine as one bundled stream, or the walking paths can be decentralised, resulting in more unbundled streams throughout the landside. Inputs for the passenger experience come from the "Landside Structures" part and from the "Existing Structures" part.

- *Respect Boundaries*: This part checks if a certain landside structure stays within the boundaries. It checks whether the outline of the landside structure crosses the boundary somewhere, if this happens a very large penalty applies, acting as a Big-M constraint. And if the certain landside structure stays within the boundaries, it calculates the distance from the middle of that landside structure to the terminal entrances. Inputs for respect boundaries come from the "Location Determination" part and from the "Boundaries" part.
- *No Overlap*: This part checks if the different landside structures do not overlap with each other. It checks whether if there is an intersection between the regions of the different landside structures, if this happens a very large penalty applies, acting as a Big-M constraint. Inputs for the no overlap come from the "Landside Structure" part.
- *Weights*: Weights must be assigned to the values derived from the passenger experience. These weights can give relative importance between the different landside structures to prioritise for example a certain mode to put it closer to the terminal. Inputs for the weights come from the "Design Input" part and from the "Passenger Experience" part.
- *Solver*: The main component of the solver cluster is the "Galapagos" component, which runs the optimisation of the model. The Galapagos component has two important inputs, the objective function (the value it tries to minimise) and a set of number sliders that it is allowed to adjust during the optimisation process. These sliders come from the "Location Determination" cluster, they define the possible positions of the landside structures but are not part of the solver itself. Galapagos varies these slider values within their allowed ranges to search for the best configuration while respecting all the constraints. Inputs for the solver come from the "Location Determination" part, from the "Weights" part, from the "No Overlap" part and from the "Respect Boundaries" part.
- *Visual Outcome*: This part creates the visual outcome of the model. The solver moves the geometries of the different landside structures around until it finds an "optimal" result. The visual outcome then consist of a figure showing the different landside structures on the landside, the walking paths from the landside structures to the terminal, and also displays the average walking distance in the middle of every landside structure. Inputs for the visual outcome come from the "Solver" part.
- *Numerical Outcome*: This part creates the numerical outcome of the model. The first thing this cluster does is presenting the KPIs, consisting of the objective value and the average walking distances from the different landside structures to the terminal. The second thing this cluster does is providing an option to look back at other options that were tried during the solving process, because the Galapagos module itself does not have this option unfortunately. This is done by adding a Python module that records the values of the number sliders that determine the location of the different landside structures. After the model solver stopped, it presents a list with values of the number sliders of the different "good" options that were considered. This makes it possible to also go back to the other options by manually changing the number sliders of the different landside structures. Inputs for the numerical outcome come from the "Solver" part.

5.5. Model Objective and Scope

The model performs a single-objective optimisation, equation 5.1 shows the objective function. The first term represents the main objective, passenger experience, which in this research is limited to walking distance while level changes and conflict points are not considered. The walking distance for each mode gets multiplied by a weight based on the peak hour value and can also be multiplied by a weight to force a designer preference (table 5.1). The second term penalises overlap between landside structures, while the third term ensures that landside structures remain within the boundaries. Both penalties are set very high and act as big-M constraints to enforce feasible layouts.

The objective function is as follows:

$$\begin{aligned}
 \text{MIN. } & \text{walking distance} \times \text{peak hour weight} \times \text{designer preference weight} \\
 & + \text{overlap} \times \text{overlap penalty} + \text{boundary} \times \text{boundary penalty}
 \end{aligned}
 \tag{5.1}$$

5.6. Model Optimisation

As already mentioned in the section 5.4 Model Structure and Logic, Galapagos is used to optimise the model. Galapagos is an optimisation tool in Grasshopper (to use in combination with Rhino) that can find a good or near-optimal solution to a problem by testing different parameter combinations.

The Galapagos solver was used for the optimisation because it is directly available in Grasshopper and does not require building a separate solver. This choice aligns with the primary goal of this research, which is to develop and test the parametric model rather than to create a new optimisation algorithm. Literature showed that Galapagos is a suitable solver for parametric modelling (Jiang et al., 2024). Galapagos also includes two solving methods, an evolutionary solver and a annealing solver, which makes it flexible enough to explore different design options. This also gives the possibility to compare both solvers and to determine which one works best for the type of problem used in this research.

The following three things need to be defined for the Galapagos solver:

- *Inputs (genes)*: parameters that Galapagos is allowed to change in the form of number sliders
- *Fitness Function*: a number (the "objective") that Galapagos tries to maximise or minimise, for this research it is minimising the walking distance
- *Solver Type*: either the Evolutionary solver (default) or the Annealing solver

Figure 5.5 shows a part of the Grasshopper model, specifically the Galapagos component (pink block) and its inputs. The different parts that make up the objective function, as described in section 5.5, are added together and then used as input for the "Fitness". These are the "walking distance", "no overlap", and "respect boundary". All the 13 input parameters showed in Table 5.2 that Galapagos is allowed to change are connected to "Genome". The addition component calculates the value of the objective function and is displayed in the panel connected to it. The bigger panel on the right presents a more detailed numerical output of the solver, also presenting the average walking distances from the different landside structures to the terminal.

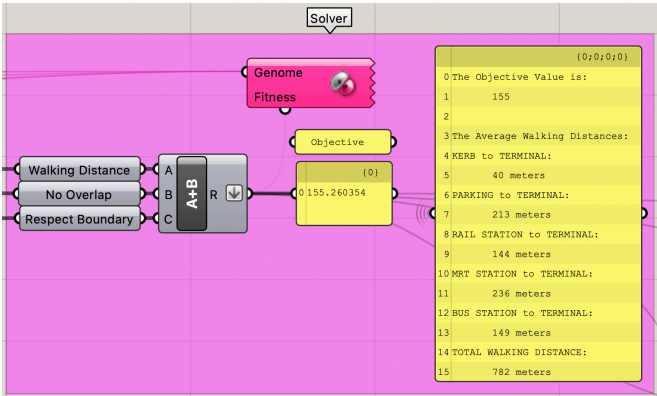


Figure 5.5: The Galapagos solver (pink module) and its inputs, together with the numerical output

Table 5.2 shows the 13 input parameters that Galapagos is allowed to change, these are all number sliders. For each of the 4 landside structures there are 3 sliders that determine the X-coordinate, Y-coordinate, and Rotation. For the parking there is an extra slider that regulates the length-to-width ratio. An example of the sliders that can adjust the input parameters for Galapagos is shown in Figure 5.6 for the rail.

To define the position of the landside structures within the landside area, number sliders were used for both the X-coordinate and Y-coordinate. Each slider ranges from 0.00 to 1.00, representing a normalized position instead of an absolute distance. In other words, the total length and width of the landside are each divided by 100, and the slider values are scaled proportionally. Because of this, the model is no longer limited by fixed dimensions, making it simple to adapt to different sizes while keeping the relative positioning.

To define the orientation of the landside structures, a rotation slider was included for each element. Depending on the landside structure, the slider either ranges from 0 to 1 or from 0 to 3 (binary rotation options), corresponding to 0°, 90°, 180°, and 270° rotations specified by a formula in another part of the model. This allows the landside structures to be tested in different orientations during optimisation without manually changing their geometry.

Table 5.2: Input parameters for Galapagos ²

Landside Structure	Design Parameter	Type	Range/Options
Parking	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1 (0°, 180°)
	Ratio Length-to-Width	Slider	1.0 - 2.5
Rail	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1, 2, 3 (0°, 90°, 180°, 270°)
MRT	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1, 2, 3 (0°, 90°, 180°, 270°)
Bus	X-Coordinate	Slider	0.00 - 1.00
	X-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1 (0°, 180°)

2. All the provided ranges are continuous ranges, the options are discrete choices indicating the rotation, the statistical significance is also shown

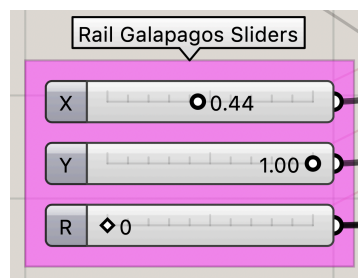


Figure 5.6: Galapagos parameters that can change the X-coordinate, Y-coordinate and rotation (example for rail)

The evolutionary solver in Galapagos searches for solutions by generating a population, evaluating their fitness. It then iteratively improves the solutions through methods such as mutation and recombination. This helps the solver to explore a wide range of configurations but sometimes causes the solver to converge prematurely on sub-optimal solutions (Tait, 2025). The simulated annealing solver uses a different approach. It starts with wide, exploratory moves and occasionally accepts worse solutions to escape local optima. As the “temperature” decreases, the search becomes more focused and controlled (Rutten, 2011). The evolutionary solver is useful for searching a large design space. The annealing solver is often better for problems with many local optima, which is the case for landside layout optimisation. Its controlled randomness helps to escape weak local optima and its gradual refinement makes convergence more reliable for this type of spatial configuration problems.

For this research, both the evolutionary solver and the annealing solver were tested. For both solvers there are different settings that can be adjusted under the options tab of the Galapagos Editor, Figure 5.7 shows the different settings that can be adjusted. The different settings and their values are explained for both solvers. Section 6.3. Optimisation Process of chapter 6. Model Outcomes explains which of the two solvers is chosen. During the optimisation process, the following factors were considered: how quickly a near optimal result can be reached, how optimal the result truly is, and which solver allows for testing a wider variety of options.

Generic

- *Fitness*: Set to Minimise, since the objective is to reduce the total value of the defined fitness function, which main component is the walking distance.
- *Threshold*: Can make the model stop if this threshold is met, but because it is difficult to estimate the optimal solution, the threshold is not set.
- *Runtime Limit*: Can make the model stop after a certain run time, but is disabled because this setting does not work properly in Grasshopper.
- *Max. Duration*: Used in combination with the runtime limit, but because the runtime limit is disabled the max duration is not set.

Evolutionary Solver

- *Max. Stagnant*: A higher number allows more generations without improvement before stopping, gives time to escape local optima. Set relatively low to prevent the model from running unnecessarily long without any major improvement.
- *Population*: A higher population explores the search space better but increases computation time. Set to a moderate value to balance exploration and runtime.
- *Initial Boost*: A higher number increases diversity in the first generation, helping the solver start from a wide range. Set to the maximum to encourage early exploration.
- *Maintain*: A higher percentage keeps more top performers. Set moderately, to keep strong candidates while encouraging new solutions to be explored and maintain diversity.
- *Inbreeding*: Controls how similar the parents can be when producing new generations. Negative values encourage exploration, while positive values lead to faster convergence. Set slightly positive to keep focus on improving good solutions while still allowing some variation.

Annealing Solver

- *Temperature*: Determines the initial level of randomness in the search. A higher temperature lets the solver explore more freely and accept temporarily worse solutions. Set relatively high to keep early exploration of different landside configurations wide.
- *Cooling*: Controls how quickly the randomness decreases. Slow cooling means more time to explore, while faster cooling starts to narrow the search earlier. Set to a moderate value to allow for exploration in the beginning while still converging in a reasonable time.
- *Drift Rate*: Determines how much the solver is allowed to explore as it cools. A higher drift rate allows more randomness in the search, helping to avoid getting stuck in local optima. A lower drift rate starts to narrow the search faster but risks converging to early. Set to a balanced value to maintain some exploration while still converging in a reasonable time.

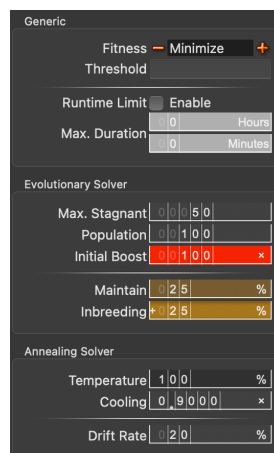


Figure 5.7: The Galapagos editor showing the generic parameters and the parameters for the evolutionary solver and annealing solver

5.7. Summary

This chapter describes the parametric model used to optimise the layout of landside structures at the airport. The model focuses on passenger experience by minimising the walking distances while respecting the boundaries and avoiding overlaps between the different landside structures. It uses data from internal NACO documents and benchmark references to define input parameters. Excel, Grasshopper, Rhino, and Python are used to process data, build the model, and visualise the results, keeping the workflow familiar and accessible for the planners and architects at NACO.

The Grasshopper file is divided into several clusters that each handle a specific part of the process, such as reading the data, creating the landside structures, defining the boundaries, checking for overlaps, and calculating walking distances. The model does a single objective optimisation, combining passenger walking distances with penalty functions for not respecting boundaries and overlap.

The model uses the Galapagos solver in Grasshopper, which has two solving methods: the evolutionary solver and the annealing solver. The evolutionary solver focuses more on improving a single solution over multiple generations, while the annealing solver explores the solution space more broadly, testing different configurations to avoid local optima. Both solvers are available for optimisation, and their performance and outcomes are analysed in the next chapter.

Overall, this chapter defines the structure, input requirements, and optimisation logic of the model. It provides the necessary basis for understanding the outcomes presented in the following chapter and supports further analysis of the different landside configurations.

6

Model Outcomes

6.1. Introduction

This chapter presents the model outcomes and is structured as follows: Section 6.2 describes the scenario setup, defining the inputs and variations tested. Section 6.3 looks at the optimisation process, showing the solver performance and logic. Section 6.4 presents the model results, providing visual outcomes for the different scenarios. Section 6.5 presents a discussion, comparing the model outcomes and linking this to the design inputs. This chapter wraps up with a summary, preparing for the conclusion & discussion chapter.

6.2. Scenario Setup

To evaluate the robustness and flexibility of the model, a number of scenarios is created that represent different demand levels and design priorities. The same model structure and constraints are used for each scenario but different input parameters and weighting factors are used for the various landside components.

The following scenarios were tested:

- **Base Scenario:** Neutral designer preferences and normal peak-hour demand levels to create a base scenario for the other scenarios.
- **High Demand Scenario:** Increased demand across all modes (+100%) to evaluate how this influences the spatial configuration.
- **Modality Preference Scenario:** Add weight to one specific mode to evaluate how designer preference can influence the location of that weighted mode.
- **Mode Fixed Position Scenario:** Fix the position of one mode to see how the other modes are optimised around it.
- **No Arrival Kerb Scenario:** Remove the arrival kerb to see the impact on the other modes, especially the parking.

Each scenario is run by the annealing solver from Galapagos to find the landside configuration that minimises the weighted walking distance while respecting the boundary and non-overlap constraints. In Table 6.1 the different scenarios are described.

Table 6.1: Overview of the scenarios and parameter settings, the base scenario is used as reference for the other scenarios

Scenario	Demand Level	Designer Preferences	Mode Weighting
Base	Normal	Neutral	Based on Demand
High Demand	+100%	Neutral	Based on Demand
Modality Preference	Normal	[MRT] x10	Weighted
Mode Fixed Position	Normal	[Rail] Fixed Position	Based on Demand
No Arrival Kerb	Normal	[Kerb] No Arrival	Based on Demand

The chosen scenarios are created to test how well the model responds to both quantitative and qualitative changes in the landside planning context. The **Base** scenario provides a reference point for interpreting the other scenarios, representing a normal demand level and equal weighting across all modes. The **High Demand** scenario introduces a 100% increase in yearly demand to evaluate how the model adapts to capacity pressure and to look at how the landside configurations adapt to this. The **Modality Preference** scenario reflects a designer driven context, where a certain weight is assigned to a mode to ensure that the model gives preference to this mode. This makes it possible to evaluate how subjective priorities influence the ideal landside configuration. The **Mode Fixed Position** scenario reflects a situation where a certain mode already has a fixed position. This makes it possible to see what would happen with the optimisation of the other modes around it. The **No Arrival Kerb** scenario removes the arrival kerb to see the effect on the other modes, especially the parking. Together, these scenarios collectively show the adaptability and interpretability of the model by representing the range between data-driven (demand based) and designer-driven (preference based) decision making.

6.3. Optimisation Process

The optimisation was done by using the built-in solvers from Galapagos within Grasshopper, in combination with Rhino. Both the Evolutionary Solver and the Annealing Solver were tested to determine which of the two performs best for the parametric landside layout problem. Both solvers were evaluated based on how well they could explore the solution space, respect the spatial constraints, produce logical layouts, and how fast it could come to a reasonable solution. To make a fair comparison, the model was run for 30 minutes for both solvers.

Since the optimisation problem includes both discrete and continuous variables, non-linear relationships, and hard spatial constraints like avoiding overlaps and respecting the boundaries, the Evolutionary Solver initially seemed to be the best choice for this research. These characteristics make the solution space highly irregular with many local optima, eliminating the use of traditional or gradient-based optimisation methods.

For the Evolutionary Solver, each run consisted of a defined population size, mutation rate, and convergence threshold, as described in Section 5.6. The solver explores the search space by iteratively adjusting the positions and orientations of the landside components to minimise the defined objective function. During the optimisation, the solver performed typical evolutionary behaviour, a rapid improvement in fitness during early, followed by slower convergence as it approached local optima. This optimisation process can be seen in the sped-up video in Figure 6.1. In several runs, small variations between outcomes were observed, reflecting the stochastic nature of the Evolutionary Solver. Initially, the solver explores a wide range of configurations (as can be seen in the first part of the video, the exploration phase). However, once the solver identifies a promising solution, it focuses on optimising that option and performs little further improvement (as can be seen in the second part of the video, the convergence phase). As a result, the final layouts often remain sub-optimal, with obvious alternative configurations that could yield better performance. This limited the ability of the Evolutionary Solver to explore alternative configurations compared to the Annealing Solver.

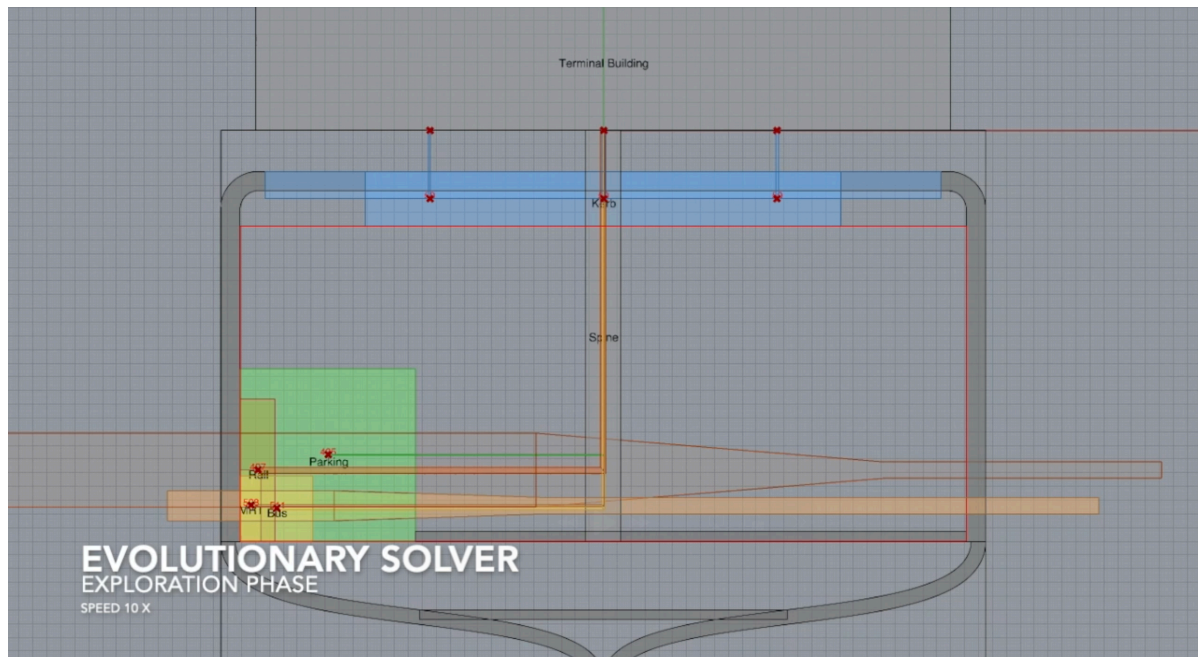


Figure 6.1: Video of the optimisation process using the Evolutionary Solver

After testing both solvers in practice, it became clear that the Simulated Annealing Solver was the better choice for this optimisation problem. Although the population-based approach of the Evolutionary Solver allows broad exploration, in practice it starts to focus too quickly on promising solutions, which limits exploration and leads to missing better alternatives. In contrast, the Annealing Solver, explores the solution space more broadly at the start of the optimisation and allows accepting temporarily worse solutions to escape local optima at the beginning. This optimisation process can be seen in the sped-up video in Figure 6.2. The solver performs multiple iterations, where for each iteration the solver starts with exploring a large number of configurations with broad and sometimes counter-intuitive moves (as can be seen at the start of the different iterations in the video, the high-temperature phase). As the temperature decreases, the solver becomes more selective and refines the most promising configurations (as can be seen at the end of the different iterations in the video, the cooling phase). The broad exploration followed by focused refinement allows the solver to reach more consistent and higher-quality solutions across the different iterations. This behaviour makes the solver more appropriate for this research, where the solution space is large, highly irregular, and contains many feasible but comparable layouts. By testing different combinations of X-coordinates, Y-coordinates, and rotations the Annealing Solver is able to discover diverse solutions and gradually converge towards near-optimal configurations.

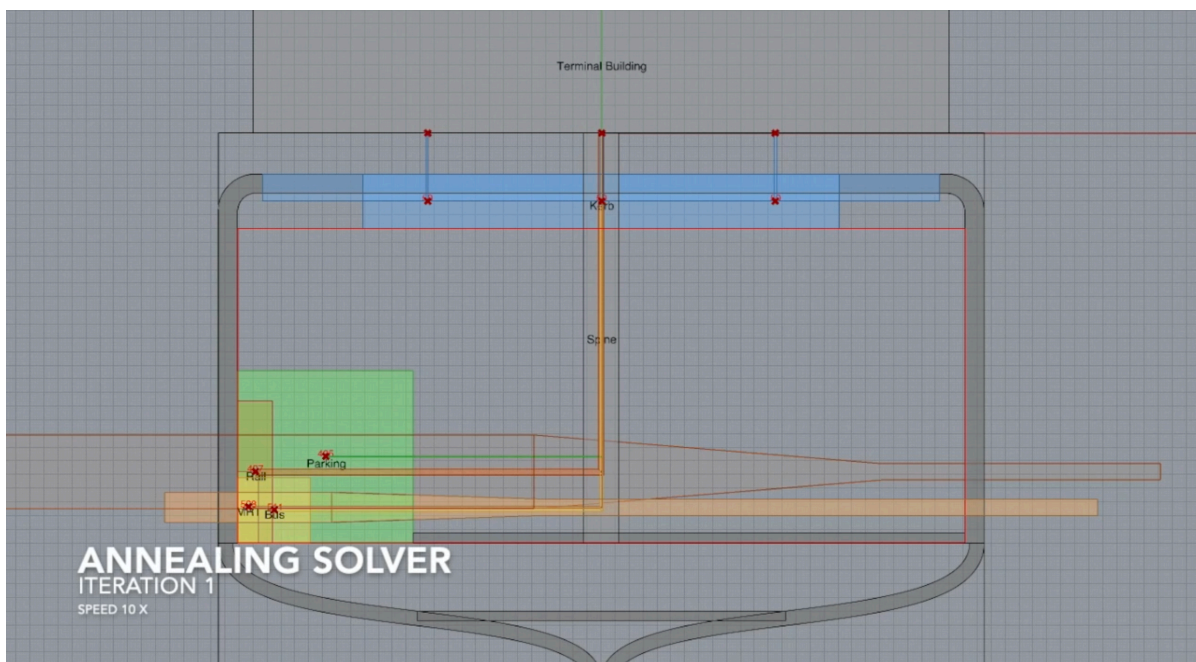


Figure 6.2: Video of the optimisation process using the Annealing Solver

The main trade-off is not computation time, but the way each solver uses this time. The Annealing Solver explores many combinations and identifies promising options, and then repeats this selection and refinement process several times in different iterations. This gradual improvement leads towards a near-optimal solution. In contrast, the Evolutionary Solver quickly goes towards one promising configuration and performs limited improvement afterward. This often results in clearly sub-optimal layouts. For this research, the Annealing Solver therefore offers a clear advantage because it explores the solution space more thoroughly and consistently delivers more optimal configurations.

6.4. Model Results

This section presents the optimised configurations for each scenario. Each Figure shows a visual outcome and a numerical outcome. The visual outcome (a) consist of the spatial configuration of the landside structures, including the roads, kerb, public transport stations, and parking, relative to the passenger terminal. The visual outcome also displays the walking paths from every landside structure to the terminal building in the same colour as the landside structure. The thickness of the path is relative to the peak hour demand that comes from that landsides structure. The numerical outcome (b) consists of the objective value and all the average walking distances from the different landside structures to the terminal. In the modelling process an attempt was made to create cross-sections, these played no role in the optimisation and therefore can be found in Appendix A.

For the landside and terminal dimensions are chosen that are realistic for an airport with 40 MAP. The option with a spine with centralised walking routes is chosen, because this represents the most realistic walking paths. For the kerb, parking, rail and MRT the parameters have been chosen to create a realistic, varied and interesting landside. This fictional landside includes a segregated kerb, a parking lot, an underground intermediate rail station, and an above-ground MRT end station. All scenarios are in basis the same. Below in Table 6.2, the selected design parameters in Grasshopper from Table 5.1 are presented. The design parameters are the same for all scenarios unless stated otherwise.

Table 6.2: Chosen design parameters grasshopper, the same for all the tested scenarios

Grasshopper Module	Design Parameter	Type	Chosen Value
Landside	Length	Slider	550
	Width	Slider	400
Terminal	Length	Slider	500
	Width	Slider	100
	Offset	Slider	30
	Entrances	Slider	3
Walking Routes Spine	Layout Option	Dropdown	0. Centralised
	Add Option	Dropdown	0. Spine
	Width	Slider	25
Kerb	Layout Option	Dropdown	0. Segregated Kerb
	Forecourt Size	Slider	20
Parking	Rental Option	Dropdown	0. Rental in STP
	Percentage STP	Slider	0.20
	Number of Floors	Slider	5
Rail	Level Option	Dropdown	1. Under Ground
	Station Option	Dropdown	1. Intermediate Station
	Built Option	Dropdown	0. Cannot Build on Top
MRT	Level Option	Dropdown	0. Above Ground
	Station Option	Dropdown	0. End Station
	Built Option	Dropdown	0. Cannot Build on Top

Besides the chosen design parameters in Grasshopper, there is also input coming from the Excel file.

- *Hard input:* 40 MAP, 4 Rail tracks, 2 MRT tracks, and 11 Bus bays.
- *Demand:* The combined Peak Hour Demand based on the MAP and combined modal splits Percentage for the passengers, airport employees and commercial employees (table 6.3).

Table 6.3: Peak Hour demands from Excel for the landside structures and the percentage distribution

Landside Structure	Peak Hour Demand	Percentage
Kerb	2035	17.9
Parking	922	8.1
Rail	4779	42.1
MRT	1465	12.9
Bus	2162	19.0

6.4.1. Base Scenario

The Base scenario provides a reference point for interpreting the other scenarios, representing a normal demand level and equal weighting across all modes. Figure 6.3 presents the visual and numerical outcome of the Base scenario.

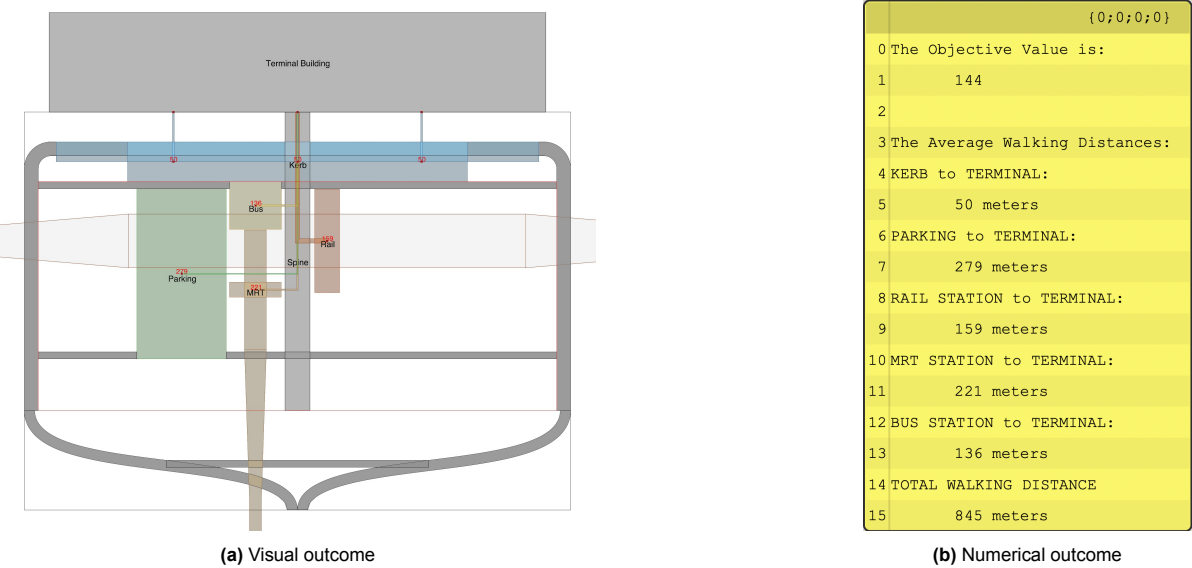


Figure 6.3: Model outcomes of the Base scenario

As can be seen in Figure 6.3 the visual outcome shows that the rail and bus are positioned closest to the terminal to reduce their walking distances. This makes sense, given that these two modes also have the highest peak hour demand. The MRT is rotated 90 degrees (starting from a horizontal position) and fits neatly under the bus station parallel to the spine, which is the closest position to the terminal considering the location of the bus and rail. The parking is then positioned to the left of the MRT, resulting in the longest walking distance for the parking, not entirely unexpected, given that peak hour demand for the parking lot is also the lowest. The parking could probably have been placed on the opposite side of the spine, to the right of the rail, for a slight reduction in the total walking distance, but the model did not do this. This is likely because several configurations produce almost identical objective values, so once the solver identified a feasible and well-performing layout on the left side, it improved that option instead of exploring alternatives on the opposite side of the spine. Overall this landside configuration seems logical and can act as a good reference points for the other scenarios in the next subsections of this section.

6.4.2. High Demand Scenario

The High Demand scenario introduces a 100% increase in yearly demand to evaluate how the model adapts to capacity pressure and to look at how landside configurations adapt to this. Figure 6.4 presents the visual and numerical outcome of the High Demand scenario.

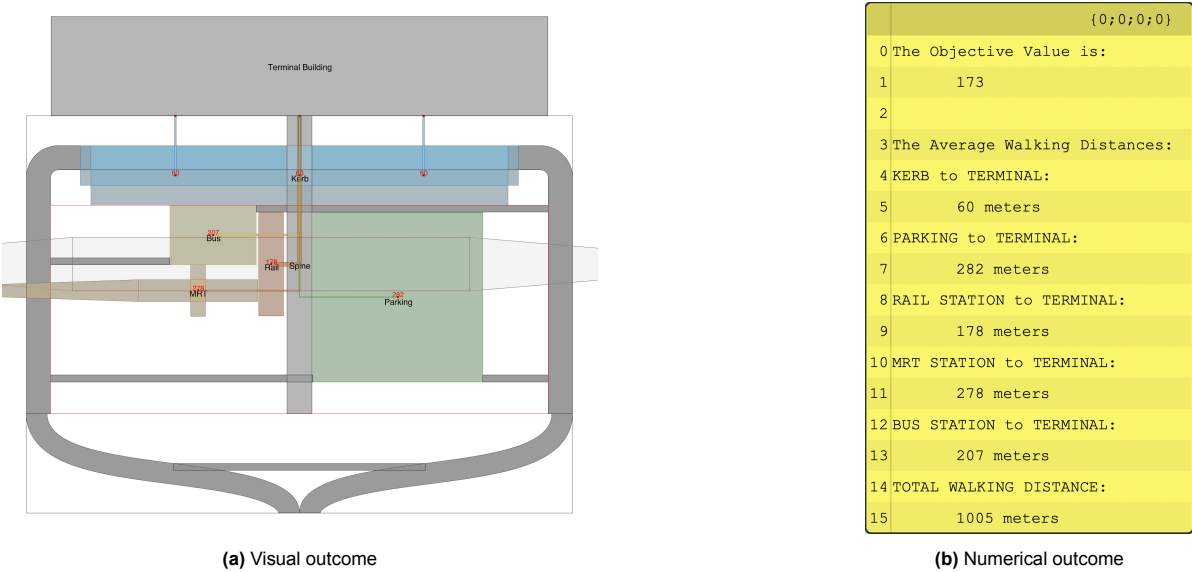


Figure 6.4: Model outcomes of the High Demand scenario

Table 6.4: KPI comparison between the Base scenario and High Demand scenario

KPI	Base Scenario	High Demand Scenario ¹
Walking Distances in m:		
Kerb to Terminal	50	60
Parking to Terminal	279	282
Rail to Terminal	159	178
MRT to Terminal	221	278
Bus to Terminal	126	207
Total	845	1005
Ground Surface in m ² :		
Parking	14400	28800
Bus	2506	5220

1. Colour coding: better than Base, same as Base, worse than Base

Table 6.4 presents a comparison of the KPIs of the Base scenario and the High Demand scenario. In the High Demand scenario, total demand doubles, so it's not entirely surprising that all walking distances have increased. The parking and bus have doubled in size, which is expected considering demand has also doubled. As can be seen in Figure 6.4 the parking now occupies almost the entire right-hand side, but it is the only mode for which the walking distance has remained approximately the same compared to the Base scenario. For the other modes of transport, the walking distance has increased more significantly. The increased width of the kerb requires additional space directly in front of the terminal, which pushes the other landside structures further away. This alone already causes a big increase in walking distance for the other landside structures. In addition the effect of the landside structures themselves becoming larger, also leads to increased walking distances. Overall the landside configuration seems logical, the different landside structures increased in size but still present a logical model outcome.

6.4.3. Modality Preference Scenario

The Modality Preference scenario reflects a designer driven context, where a certain weight is assigned to a mode to ensure that the model gives preference to this mode. This makes it possible to evaluate how subjective priorities influence the ideal landside configuration. Figure 6.5 presents the visual and numerical outcome of the Modality Preference scenario. For this scenario, preference is given to the MRT.

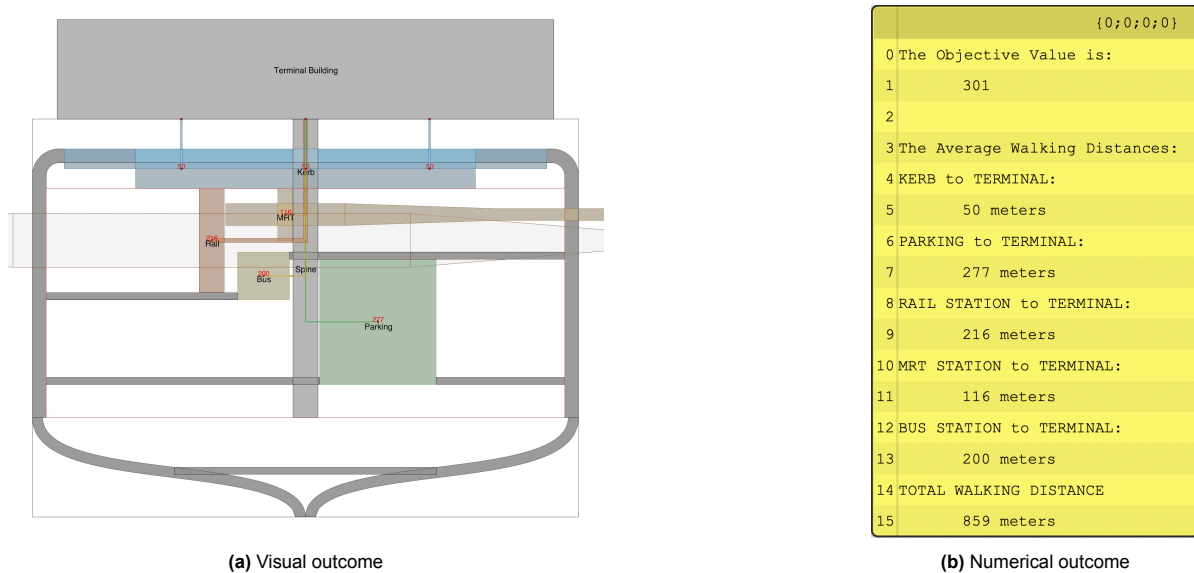


Figure 6.5: Model outcomes of the Modality Preference scenario (MRT preference)

Table 6.5: KPI comparison between the Base scenario and Modality Preference scenario (MRT preference)

KPI	Base Scenario	Modality Preference Scenario ²
<i>Walking Distances in m:</i>		
Kerb to Terminal	50	50
Parking to Terminal	279	277
Rail to Terminal	159	216
MRT to Terminal	221	116
Bus to Terminal	126	200
Total	845	859
<i>Ground Surface in m²:</i>		
Parking	14400	14400
Bus	2506	2506

2. Colour coding: better than Base, same as Base, worse than Base

Table 6.5 presents a comparison of the KPIs of the Base scenario and the Modality Preference scenario. In the Modality Preference scenario, the preferred mode gets assigned an extra weight based on input from the designer. In this case the weighted walking distance from the MRT gets multiplied by a factor 10, really forcing the model to place the MRT close to the terminal, which can be seen in Figure 6.5. This can also be seen in Table 6.5, where the walking distance for the MRT has been almost halved. The walking distance to the kerb and parking has remained approximately the same. For the Rail and Bus the walking distance has increased due to the sup-optimal landside configuration, which also results in a higher total walking distance. This makes sense as rail and bus represent a large part of the total demand (see Table 6.3). Overall the landside configuration seems logical, the different landside structures are placed around the MRT with the modes with the highest demand being the closest.

6.4.4. Mode Fixed Position Scenario

The Mode Fixed Position scenario reflects a situation where a certain mode already has a fixed position. This makes it possible to see what would happen with the optimisation of the other modes around it. Figure 6.6 presents the visual and numerical outcome of the Mode Fixed Position scenario. For this scenario, the position of the Rail is fixed.

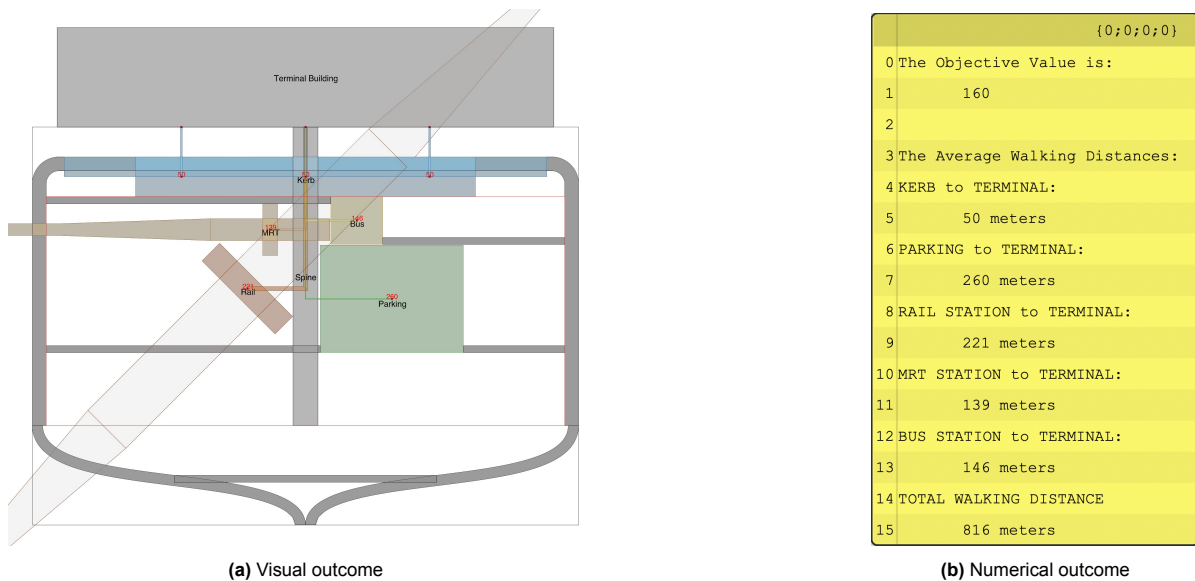


Figure 6.6: Model outcomes of the Mode Fixed Position scenario (Rail fixed position)

Table 6.6: KPI comparison between the Base scenario and Mode Fixed Position scenario

KPI	Base Scenario	Mode Fixed Position Scenario ³
<i>Walking Distances in m:</i>		
Kerb to Terminal	50	50
Parking to Terminal	279	260
Rail to Terminal	159	221
MRT to Terminal	221	139
Bus to Terminal	126	146
Total	845	816
<i>Ground Surface in m²:</i>		
Parking	14400	14400
Bus	2506	2506

3. Colour coding: better than Base, same as Base, worse than Base

Table 6.6 presents a comparison of the KPIs of the Base scenario and the Mode Fixed Position scenario. In the Mode Fixed Position scenario, the position of the Rail is fixed with a rotation of 45 degrees (starting from a horizontal position) based on input from the designer, this can be seen in Figure 6.6. The other modes need to be optimised around the Rail and as close as possible to the terminal. Again, the model places the modes with a higher demand, MRT and Bus, closest to the terminal. Table 6.6 shows some interesting walking distances, compared to the Base scenario the total walking distance improves. This can be explained by the fact that the Rail now has a rotation that the model normally does not allow, only multiples of 90 degrees are normally possible. This different rotation provides other possibilities for arranging the landside. Overall the landside configuration seems logical, the different landside structures are placed around the Rail with the modes with the highest demand being placed the closest to the terminal. However, it is striking that the total walking distance has decreased. This is striking because fixing the position of the Rail restricts the design freedom of the solver. Restrictions would typically lead to a worse or at best comparable objective value. The fact that the total walking distance improves, suggests that the fixed rotation of 45 degrees opens up a landside configuration the solver could not access under the multiple of 90 degrees rotation constraint.

6.4.5. No Arrival Kerb Scenario

The No Arrival Kerb scenario removes the arrival kerb to see the effect on the other modes, especially the parking. This is an interesting option to look into as it would free up a lot of space directly in front of the terminal, allowing other modes to be placed closer. Figure 6.7 presents the visual and numerical outcome of the No Arrival Kerb scenario.

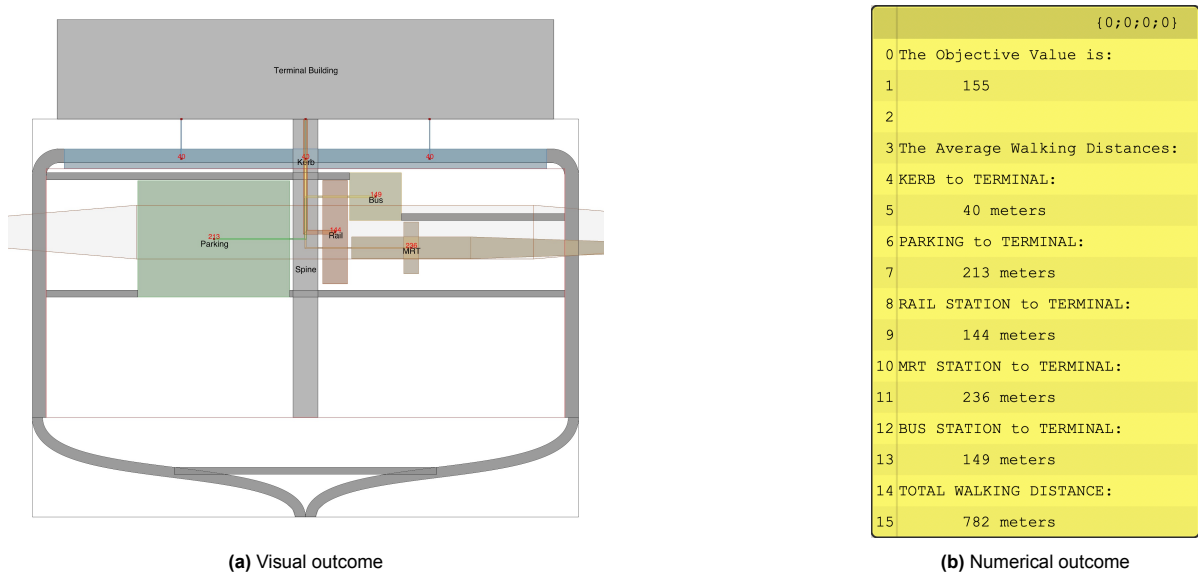


Figure 6.7: Model outcomes of the No Arrival Kerb scenario

Table 6.7: KPI comparison between the Base scenario and No Arrival Kerb scenario

KPI	Base Scenario	No Arrival Kerb Scenario ⁴
<i>Walking Distances in m:</i>		
Kerb to Terminal	50	40
Parking to Terminal	279	213
Rail to Terminal	159	144
MRT to Terminal	221	236
Bus to Terminal	126	149
Total	845	782
<i>Ground Surface in m²:</i>		
Parking	14400	17780
Bus	2506	2506

4. Colour coding: better than Base, same as Base, worse than Base

Table 6.7 presents a comparison of the KPIs of the Base scenario and the No Arrival Kerb scenario. In the No Arrival Kerb scenario, the arrival kerb gets removed. Figure 6.7 shows that simply removing the arrival kerb already brings all modes closer to the terminal, reducing the walking distances for almost all modes. This can also be seen in Table 6.7. Only for the bus and MRT the walking distance has increased slightly, but this is minimal. Due to the removal of the arrival kerb, additional space must be reserved in the parking where the drop-off of people will in this scenario take place. This can be seen in Table 6.7, where the ground surface area of the parking has increased. Overall the landside configuration seems logical, the different landside structures can all be placed closer to the terminal as a result of removing the arrival kerb, leading to a decrease in total walking distance compared to the base scenario.

6.5. Discussion of Model Outcomes

Together, the scenarios show that the parametric model can produce logical and interpretable landside configurations that react as expected to the different parameter inputs. What can be seen in all scenarios is that the model consistently places modes with the highest demand closest to the terminal, this shows that the objective function works as intended. The relationship between the demand and the proximity to the terminal reflects realistic planning logic and user priorities from the model.

When looking at the different model outcomes individually, certain results stand out. The **High Demand** scenario showed that an increased demand leads to bigger landside structures and an overall increase in walking distance across all modes. Mainly because of the increased land size requirements and the extra kerb width. The **Modality Preference** scenario shows the capability of the model to incorporate designer preferences. This is done by increasing the weight of one mode significantly, so that the solver favours this mode and places it closer to the terminal compared to the "ideal" configuration. The **Mode Fixed Position** scenario shows how constraints, created by existing structures, influence the optimisation results. Fixing the position of the rail led to a slightly lower total walking distance, as result of the additional rotation freedom. This may suggest that certain ranges or options could maybe be formulated differently, leading to improved results. However, the trade-off between a larger solution space and the solvability remains crucial. Finally, the **No Arrival kerb** scenario was interesting because it showed how the removal of a certain element of a landside structure can improve overall accessibility. Without the arrival kerb, it was possible for other modes to be placed closer to the terminal, reducing the total walking distances and showing the potential advantages of a more compact landside layout. This also suggests that alternative configurations, such as shared kerb zones, reduced buffer areas, tighter clustering of modes, or even vertical stacking of certain landside functions, may be feasible options to further improve landside efficiency.

When comparing the model outcomes of all the scenarios with each other, certain patterns can be seen. Table 6.8 shows the different KPIs from all scenarios in one overview, where a result is coloured green if it is the (shared) best performing scenario and where a result is coloured red if it is the worst performing scenario. The **High Demand** scenario is performing the worst across all scenarios considering walking distance, just not in "rail to terminal" walking distance. This is not entirely surprising, as demand is also twice as high. The **Mode Fixed Position** scenario has the biggest "rail to terminal" walking distance. This can be explained by the fact that in this scenario, the rail is fixed at a specific position much further from the terminal. In all other scenarios, the rail is placed as close as possible, because rail creates a lot of demand. The **No Arrival Kerb** scenario is performing the best across all scenarios considering the walking distance, just not in "MRT to terminal" and "Bus to terminal" walking distance. That is because only in this scenario there is more space directly in front of the terminal. The **Modality Preference** scenario has the lowest "MRT to terminal" walking distance, this shows that the designer is able to give preference to a certain mode. All together, the overview provided by Table 6.8 does not show any strange results when comparing the different scenarios.

Table 6.8: KPI comparison between the Base scenario and all other scenarios

KPI ⁵	Base Scenario	High Demand Scenario	Modality Preference Scenario	Mode Fixed Position Scenario	No Arrival Kerb Scenario
<i>Walking Distances in m:</i>					
Kerb to Terminal	50	60	50	50	40
Parking to Terminal	279	282	277	260	213
Rail to Terminal	159	178	216	221	144
MRT to Terminal	221	278	116	139	236
Bus to Terminal	126	207	200	146	149
Total	845	1005	859	816	782
<i>Ground Surface in m²:</i>					
Parking	14400	28800	14400	14400	17780
Bus	2506	5220	2506	2506	2506

5. Colour coding: best result, worst result

Overall, the results show that the model responds predictable and accurate to the changing quantitative and qualitative inputs represented through the different scenarios. The model outcomes are interpretable and in line with the common sense of planning, while also offering new insights in spatial relationships and trade-offs between design decisions. The tested scenarios demonstrate how the model handles different situations, providing evidence of its validity and potential to support decision-making. The ability to adapt to these different scenarios shows that the model has potential to support early stage master planning.

A thorough sensitivity analysis was not conducted, because it falls outside the intended scope of this research and would not significantly improve the results of the research. The model was created as a conceptual and exploratory tool for the early phase planning, instead of a calibrated prediction model that requires extensive robustness testing. The scenario-based approach used in this research already functions as a sort of structured sensitivity analysis, since both quantitative inputs (such as demand levels) and qualitative parameters (such as design preferences and spatial constraints) were changed deliberately to see how they affected the model outcomes. Moreover, the model is based on generalised assumptions and simplified geometries of an imaginary airport, meaning that a numerical sensitivity analysis would not produce meaningful or transferable results. In addition, the stochastic behaviour of the simulated annealing solver already introduces variability across runs. This already indirectly exposes the model to different parameter settings. For these reasons, the behaviour of the model across the designed scenarios provides sufficient validation for its purpose, and a thorough sensitivity analysis was not deemed necessary.

6.6. Summary

This chapter presents the scenario setup, optimisation process, and model results of the parametric model. This chapter expanded on the model structure and logic provided in the previous chapter, showing how the model performs under different planning scenarios.

In the scenario setup section, multiple fictional scenarios were created to evaluate the flexibility and sensitivity of the model. The Base scenario serves as a reference point for the comparison with the other scenarios, which included the High Demand, Modality Preference, Mode Fixed Position, and No Arrival Kerb scenarios. It tested how the model would react to quantitative changes in demand and qualitative changes in design priorities and spatial constraints. Together, these scenarios provide a framework to evaluate both data-driven and designer-driven decision contexts.

The optimisation process section compared the performance of the evolutionary solver and the annealing solver. The evolutionary solver initially seemed the most suitable solver because of the balance between exploration and convergence, however it tended to focus too early on local optima. The annealing solver, on the other hand, seemed to be more suitable for this problem. The exploration was more broadly and looked at more diverse landside configurations. The parameters for the annealing solver were tested and adjusted to produce consistent results within a reasonable time.

Finally, the model results section showed that the model can create logical and consistent landside configurations that adjust to the changing inputs. The model outcomes reflected clear cause-and-effect relationships, like higher demand resulting in larger surface requirements and therefore increased walking distances. The scenarios also behaved in line with expected planning logic, such as the preferred mode being placed closest to the terminal. In conclusion, the results show the potential of the model to be of use in early-stage master planning as a supporting tool.

Overall, this chapter shows that the parametric model is capable of adapting to different design inputs, while providing useful insights in how demand, designer preferences, and spatial constraints influence the landside configurations. These findings form the basis for the following chapter where the conclusion, discussion, and recommendations are presented.

Conclusion & Discussion

7.1. Introduction

The development of the parametric model for the airport landside of passenger terminals demonstrates the potential of how automation can support early-stage design and decision making by structuring complex spatial relationships and allowing designers to explore different layout configurations more systematically. Instead of proving that parametric modelling can replace existing design practices, the research highlights both the potential and the limitations of the use of a parametric model. The model shows how key parameters interact, allows faster iteration of different designs compared to manual sketching, and could provide more informed discussion between designers and clients. At the same time, during the research it becomes clear that imitating the flexibility, intuition, and creativity of human designers remains challenging. This is especially the case when dealing with irregular geometries or unconventional layouts. The model was not tested on such irregular geometries, and therefore its applicability outside standard configurations cannot be proven. Overall, the research presents a conceptual model of how parametric methods could structure early-phase landside planning, while also realising that further development is required before it can be used as a robust, widely useable design tool.

This final chapter summarises the findings of this research and reflects on the limitations of the developed parametric model. Section 7.1 presents the conclusions, summarising the main outcomes and addressing all the research questions. Section 7.2 discusses the limitations of the model and the challenges encountered during its development. Finally, section 7.3 provides recommendations for further research and for NACO, explaining how the parametric model approach could be further improved and applied within future projects.

Ultimately, this chapter answers the main research question:

In what way can a parametric model facilitate the generation and evaluation of adaptable landside configurations for terminal landside structures?

7.2. Conclusion

This research presents a parametric model framework, supported by a functioning prototype model, that enables the automated generation of airport landside configurations for airport passenger terminals. In chapter 1, a set of research questions was formulated, which collectively try to answer the main research question. This section summarises the findings for each research question, every paragraph focusses on one of the three sub-questions. This section concludes by answering the main research question.

Research Question 1:

How are airport landside structures for passenger terminals currently sized and designed, and which design rules can serve as input for a parametric model?

(a). An airport landside acts as the interface between the terminal and the wider transport network, accommodating private vehicles, taxis, buses, rail, and MRT. Each mode requires dedicated infrastructure, such as access roads, kerbs, parking, and public transport stations, all positioned in close proximity to the terminal. Designing the layout requires separating the different traffic flows while also ensuring efficient passenger movement and accessibility.

(b). The literature describes that most airport landside planning is still based on static forecasts and “rules of thumb” derived from design guidelines provided by IATA, ICAO and ACRP reports. These methods are straightforward and effective for producing quick baseline estimates, and they can even provide some future flexibility by allowing designers to adjust capacities when forecasts change. However, this flexibility is limited because rules of thumb typically result in a single solution instead of looking at a quick exploration of different alternatives. As a result, these methods limit the ability to adapt to site-specific conditions or explore a wide range of design alternatives (Dimitriou et al., 2025, Jones and Pitfield, 2007). In addition, public transport integration is not embedded well enough in the current design process, although it is becoming increasingly important for reducing car use and improving connectivity (Fang and Zimmerman, 2015, Mrníková et al., 2017). Traditional methods seem to lack integrated data-driven tools that evaluate landside design decisions. A parametric decision support tool could assist airport planners in quickly testing different layouts and public transport scenarios, making the design process more adaptive. However, adopting such a method would also require early involvement of parametric modellers and computational designers, which may not be feasible given the different structures and skill sets of every project team.

(c). Sizing of the individual landside structures, such as the access roads, parking, and kerb, is traditionally based on peak hour or design day demand. These numbers are derived from flight schedules or annual passenger forecasts. To determine how the demand is distributed over the different modes, modal splits are used. Although this approach ensures sufficient capacity during the busiest periods, it often results in more than needed over dimensioning of infrastructure that remains underutilised most of the day, reducing cost-efficiency. The traditional approach provides a solid baseline, but it remains limited in its ability to explore alternative layouts or evaluate interactions between different landside components. This means that system level optimisation, coordinated improvements across all modes, is still difficult to get to. In this research, the developed model also uses peak-hour demand as input. The added value of the model is that it allows designers to iteratively reposition, resize, and combine landside structures to learn how capacity requirements affect the entire landside layout. Instead of improving the forecast itself, the model provides insight into how different spatial configurations perform under the same demand assumptions. The public transport stations are particularly difficult to size, because their demand depends not only on peak demand but also on the place of the station in the wider transportation network. Through expert consultation some rule-of-thumbs were determined to be able to size those public transport stations. Although rule-of-thumb inputs remain necessary, the parametric framework allows them to be used in a more flexible way by testing how the different landside structures interact with each other in the broader landside layout. So, rules-of-thumb still define baseline requirements, but the parametric model enables designers to explore multiple ways of meeting them.

Research Question 2:

What are the key design parameters for modelling airport landside performance, with particular attention to passenger experience?

(a). The system analysis conducted in this research identified three groups of design parameters that are essential for modelling airport landside performance: *demand parameters*, *spatial parameters*, and *performance indicators*. *Demand parameters* include the passenger demand, modal splits, arrival/departure profiles, and temporal fluctuations. These parameters determine the intensity and variability of the landside use. The parameters directly influence the required capacity and operational characteristics of the landside structures, such as: roads, parking, kerb, and public transport stations. *Spatial parameters* determine the geometric and physical constraints of the landside area, such as the terminal footprint, available land envelope, the road configuration, and possible location of the transport modes. These parameters form the structural foundation of the parametric model and were translated into quantifiable model inputs that can be varied systemically to generate multiple landside configurations automatically. *Performance indicators* provide measurable outcomes that guide the optimisation process and allow configurations to be compared to create optimal landside configurations. In the model, these include not only the objective value from the optimisation but also the walking distance which captures the passenger experience. The level changes and conflict points were left out of the parametric model, because this would have required a 3D component, complicating the model too much for this research. It is clear that looking only at walking distance does not fully capture the passenger experience, but it does provide a quantifiable parameter that can be optimised.

(b). Passenger experience was considered as an important, but challenging design aspect. In the parametric model, passenger experience is primarily represented through the average walking distances between each landside structure and the terminal entrances. Walking distance was used as an estimate for accessibility and convenience, allowing the model to quantify and compare the alternative landside configurations on passenger experience. However, passenger experience consists of more than walking distance alone. Additional aspects, such as level changes, conflicts points, and passenger flow separation, also influence how passengers perceive and navigate the landside environment. Several of these aspects could be incorporated into a parametric approach, for example by penalising level changes or conflict points. Although these aspects were not included in the current parametric model due to scope and abstraction level, the walking distance provides a consistent and scalable starting point for evaluating passenger experience during the early design phase.

(c). Parametric and generative design methods used in other fields like architecture and urban planning provide a strong foundation for improving airport landside planning. Since landside environments share characteristics with complex urban planning projects, therefore methods from these fields are directly relevant. Existing studies demonstrate how parametric frameworks can integrate geometric rules with performance-based evaluation to automatically generate and assess design alternatives (Weber et al., 2022, Laignel et al., 2021, Jiang et al., 2024, Bielik et al., 2022). These approaches demonstrate how iterative, data-driven methods can help support early-stage design by making it possible to quickly explore alternatives and adapt to future changes. Translating these methodologies to airport landside planning can help the field move from static, conventional methods towards more dynamic and data-driven design methods. This offers new opportunities for flexibility, transparency, and systematic comparison during the early design decision-making.

Research Question 3:

What is needed for a parametric model to generate airport landside configurations based on different scenario inputs, and how can these be evaluated?

(a). The model required passenger demand data, modal splits, and the basic geometries representing the landside structures to generate realistic landside configurations. To provide these inputs, an Excel file was used, making it simple to change inputs and test different scenarios. The use of Excel made it also easier to integrate it with the workflows from NACO and made it possible for the model to adapt to different airport contexts. By separating the data input from the geometric generation, a framework was created where data and design could be updated independently, supporting the iterative scenario analysis.

(b). Using these different data inputs, the model could generate different landside configurations automatically within the Grasshopper environment. The Grasshopper model fulfils three main functions, that can be seen as three steps that are performed one after the other. The first function of the Grasshopper model is the translation and visualisation of the input data from the excel to geometries. The second function is the optimisation of the spatial layout. The annealing solver from Galapagos was used to optimise the landside configuration by minimising the average walking distance between the modes and terminal entrances. The optimisation process explored numerous options, restricted by different constraints such as the boundaries and the no overlap. The third and final function of the Grasshopper model is the evaluation of the resulting layout. Five scenarios (Base, High Demand, Modality Preference, Mode Fixed Position, and No Arrival Kerb) were tested, each demonstrating how the model adapts to quantitative and qualitative changes. The generative capability of the model allows planners to explore the different designs efficiently and makes them understand the spatial implications of design choices.

(c). The landside configurations from the different scenarios were evaluated through both quantitative and qualitative analysis. For the quantitative analysis, the optimisation results were compared using the average walking distances for the different modes and the total walking distance. For the qualitative analysis, the spatial configuration of each scenario was reviewed. This evaluation approach provided both analytical and visual feedback to support informed decision-making. Overall, the results show that the model responds predictably and accurately to changes in both quantitative and qualitative inputs across the scenarios. The outcomes are interpretable and align with common planning logic, while also revealing new insights into spatial relationships and trade-offs between design choices. The tested scenarios illustrate how the model handles different design inputs, providing evidence of its validity and its potential value in supporting decision-making. This ability to adapt to different planning contexts indicates that the model can be of use for early-stage master planning. However, the Galapagos solver can still be seen as a "black box", presenting only the final result and not the optimisation process itself. This limitation, together with the stochastic nature of the solver, model outcomes can vary between runs. Therefore, a sensitivity analysis is recommended to evaluate how changes in inputs and solver settings influence the results and to improve the trust in the reliability of the model.

Main Research Question:

In what way can a parametric model facilitate the generation and evaluation of adaptable landside configurations for terminal landside structures?

This research demonstrates that the use of a parametric model can support, rather than fully automate, the generation and evaluation of adaptable landside configurations. By translating demand, spatial, and performance parameters into a structured, data-driven framework, the model provides a systematic way to explore design alternatives. Unlike the traditional methods, which rely heavily on manual iteration, the parametric model approach enables the automatic generation and comparison of different design alternatives based on consistent input data and predefined geometries. Through the use of the integrated data input from excel, the geometric generation of the landside structures, and the annealing solver, the model shows how early-stage design exploration can be partially automated. At the same time, the research demonstrates that the support from the parametric model remains constrained by the model abstractions, simplifications, and the capabilities of the tools used.

The results show that a parametric model can help with the early design process, producing different landside configuration within minutes, and improving the decision making by making trade-offs between the spatial configurations and passenger experience more clear. However, the implementation is only partial, the parametric model does not capture not all the essential features of passenger experience, such as level changes, conflict points, and passenger flow separation. Because walking distance is the only feature that has been quantified, the model provides insight into one specific dimension of accessibility rather than the broader passenger experience. Nonetheless, using walking distance as an objective helps planners to compare the relative impact of different landside configurations and makes certain spatial trade-offs easier to interpret at a conceptual level. The research also indicates why parametric modelling is not yet widely adopted in airport planning, the method requires specialised skills, changes to established design methods, and careful handling of model abstraction to avoid oversimplification. Recognising these limitations helps to position the model as an early-stage support tool that can supplement, rather than replace, traditional design methods.

The model also highlights several methodological and practical limitations that affect its reliability and broader applicability. The optimisation modules within Grasshopper, particularly the Galapagos solver, offers limited transparency about the optimisation process and gives slightly different results between the different runs, which complicates the interpretation of results. Besides that, the high abstraction level used in this research poses some challenges and limitations. Solving a 2D problem of the landside while it is actually a 3D problem, and using a simplified representation of the passenger experience, means that the model cannot completely capture the full complexity of real-world landside systems right now. Therefore, the parametric model should be viewed as an exploratory tool rather than a predictive or fully operational design method.

Despite these limitations, the developed framework shows that a parametric model can be a potential useful tool in the early stages of landside planning. It supports planners and clients in exploring design alternatives and helps with discussions based on measurable performance indicators, helping create a more adaptive and collaborative design process. The research also provided important lessons on parametrisation, optimisation, and the representation of passenger experience, highlighting both the potential and the current constraints of this approach. The main conclusion of the research is that a parametric model can make landside planning more adaptable, transparent, and data-driven. At the same time, this research represents only a first step, major challenges remain. This includes the integration of 3D geometries, extended passenger experience inclusion, and a more transparent optimisation process before this approach can be fully developed and applied in practice.

7.3. Discussion

The parametric model that was created shows the potential of automation on supporting early-stage decision making in the airport landside planning context. It offers a way to generate and evaluate designs in a much shorter time and provides a structured integration between demand, geometries, and performance. However, some simplifications that have been made to create this framework introduce significant limitations that have an influence on the accuracy and applicability of the model.

A first limitation is the representation of passenger experience, which in this research was only defined through average walking distance. While this provided an easily understandable and quantitative objective for the optimisation, it only partly captures the passenger experience. Factors such as level changes and conflict points, were not considered. Another limitation of the model, that follows from a simplification of the reality, is that the model only looks at 2D landside configurations. Most landside areas are three-dimensional, with multiple levels connected by ramps, stairs, or elevators. A 3D model output or cross sections can help to cover the three-dimensionality of the problem, also allowing the model to incorporate level changes as part of the passenger experience more easily.

A second limitation comes from the behaviour of the solver used for the optimisation. The Galapagos solvers act as a "black box", where the only outputs are the final objective value and visual landside configurations. Little is known about the optimisation process itself. The nature of the annealing solver also introduces a degree of randomness, meaning that varying outcomes can occur for every run. While this is acceptable for exploratory analysis and scenario testing, its impact is relatively smaller compared to other limitations, such as the simplified 2D representation of the landside and the limited modelling of passenger experience. This limitation can be addressed by creating clearer boundaries or exploring alternative solvers, improving the consistency, interpretability, and confidence of the model outcomes.

Finally, the model depends on multiple generalising assumptions to represent the landside system at a preliminary conceptual level. In this context, the conceptual level refers to capturing the core components of the landside, such as the access roads, kerb, parking, and public transport stations, without fully modelling all operational or geometric complexities. The parameters to create the different landside structures were derived from literature, expert consulting, and internal (Excel) documents. The model was tested with a simple, linear terminal layout with standard access configurations. These simplifications allow the model to quickly generate and compare alternative layouts for scenario analysis across different planning contexts. However, these simplifications also limit the applicability of the model for airports with more complex or unconventional configurations, such as terminals with multiple concourses, irregular kerb layouts, or stacked structures. As a result, the model outcomes should be used primarily for relative performance comparisons and decision support guidance, instead of exact design solutions. So for now caution is advised when applying the model straight to unusual airport layouts

Despite these limitations, the model shows the potential of using a parametric design approach to make the early stages of airport planning more data-driven, transparent, and adaptable. The framework provides a foundation for future research, especially when looking at adding a more detailed representation of passenger experience, improved optimisation methods, and integration of a 3D design component.

7.4. Recommendations

7.4.1. Recommendations for Further Research

The first direction future research should look into is alternative optimisation approaches that can be used in Grasshopper. The Galapagos solver was useful for testing the concept, but offers limited transparency about what happens during the optimisation process, offers limited input parameters, and very limited numerical output, only providing the objective value. Alternative optimisation approaches can be other plug-ins like Galapagos or it can be a solver completely developed through the Python modules in Grasshopper, both options are still inside of Grasshopper and make use of Rhino for the visualisation. Another option could be implementing the model completely outside of Grasshopper. For instance, in Python with an integrated visualisation component. This would make the tool more flexible and easier to expand. A downside of this option is that creating the visualisation part can take a lot of time and is less optimal compared to use of Rhino which is still very suitable for parametric design. Finally, in some way this problem looks a bit like a bin packing problem or facility problem layout with some extra and different constraints. Adapting algorithms from these domains could be an interesting option to test, taking a different approach and potentially offering faster convergence and more structured solutions.

A second direction future research can look into is expanding the scope of the model and its key performance indicators. The created model of this research focuses for the passenger experience only focusses on walking distance. Future research can extend this by adding for example level changes, conflict points, passenger flow separation, or other relevant factors. Besides that, there can also be looked at expanding the landside representation by including cargo areas or commercial functions like hotels and offices. This would help create a more realistic and complete landside system. However, adding more components to the model will most likely result in it becoming more difficult to solve and taking longer to converge, so this should probably go hand in hand with another type of solver. Lastly, adding a 3D component can also be a good direction to look into. A lot of times, this problem is in fact a 3D problem, with relationships and connections between different levels. In the process of this research an attempt was made to add this 3D component in the form of cross sections, shown in the Figures in Appendix 6.4. However due to time constraints and the limitations of the solver, the cross sections did not play a role in the optimisation part the model. By incorporating the cross sections in the optimisation part the model, valuable spatial and vertical insights could be provided, improving the analysis of the different design alternatives.

The last direction future research could focus on, is getting rid of second step of the Grasshopper model, the automatic solver part (see section 5.3 and Figure 5.2). This allows more focus to be placed on the third step, the analysis of the KPIs of the different design alternatives. For this there can still be made use of Grasshopper in combination with Rhino, but a solver like Galapagos will not be used. Instead of letting the solver determine the locations of the landside structures at the second step, this can be done manually by the planner. This could lead to a significant simplification of the model. This alternative approach would keep the flexibility of parametric modelling while the designer gets more control over the layout. Furthermore, it would be interesting to see if the same methodological framework could be applied to terminal interior design, airside layouts, or certain parts of it.

7.4.2. Recommendations for NACO

For NACO, the next step lies in deciding whether the model should focus more on generalisation or on specialisation. A generalised version of the model could focus on adapting to different airport layouts and configurations, this would make the model suitable for a wider range of projects. On the contrary, a more specialised version of the model can be developed, focusing on one single typology that is used most commonly. This can for example be a linear terminal with parallel access roads, similar to the model of this research. Both approaches provide advantages for different use cases, depending on the goal from NACO. The model can help in very early stage exploration helping choose the ideal airport layout and configuration, or the model can be used as a more precise tool that can be used for a specific airport in a later stage of master planning. In this later stage of planning, when the different landside structure geometries are known, these geometries can be used as input instead of numbers from excel sheets. This allows the model to skip the whole process of creating the geometries of the landside structures from excel numbers, which can be a very extensive step. I would suggest to focus on generalising the model, so that it could be used on a wider range of airports. This also keeps the model at a lower level of detail, which probably still makes the problem simple enough to solve with a solver.

Another topic NACO can explore is integrating the model more closely with NACO's existing workflows and data. Right now, the model of this research makes use of a simplified Excel file based on the extensive Excel file already used by NACO. For NACO it would be useful to directly connect the extensive Excel to the model, this would streamline the data exchange and workflow. Additionally, adding an interactive dashboard or web interface could make the tool more accessible for people at NACO who do not work directly with Grasshopper and Rhino. This would also improve the collaboration between NACO and external stakeholders, such as airport authorities, architectural firms, or consultancy partners involved in the planning process.

Finally, it could be explored whether the underlying concept of this parametric model (a combination of data-driven design, visualisation, and performance evaluation) might be applied in other domains within Haskoning, as NACO is part of Haskoning. For example, in urban mobility, the model could automatically generate street or network layouts based on expected demand and network constraints, and evaluate them using KPIs such as travel time, capacity, or accessibility. In infrastructure planning, parametric tools could test multiple road or terminal configurations against cost, spatial, and operational metrics. In master planning, the approach could quickly visualise different land-use plans and their impact on accessibility, connectivity, and service levels. In all cases, the combination of automated generation, KPI-based evaluation, and visual feedback would help to speed up early-stage design while keeping critical design parameters and performance indicators explicit and transparent. Additionally, intuitive visualisation and interactive interfaces could increase the usability for various stakeholders, including airport owners, operators, and planners, improving understanding and supporting collaborative decision-making.

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AI statement

For this thesis I used AI in several ways. I used AI to ask for feedback on text I wrote and on figures that I made. In addition, I have mainly used AI to translate my ideas into working modules in Grasshopper and to help with coding for Python modules in Grasshopper. The AI tool that I have used is: ChatGPT.

A

Cross Sections

In the process of this research an attempt was made to add a 3D component in the form of cross sections, shown in the Figure A.1, corresponding to the different scenarios from chapter 6.4. However due to time constraints and the limitations of the solver, the cross sections did not play a role in the optimisation part the model.

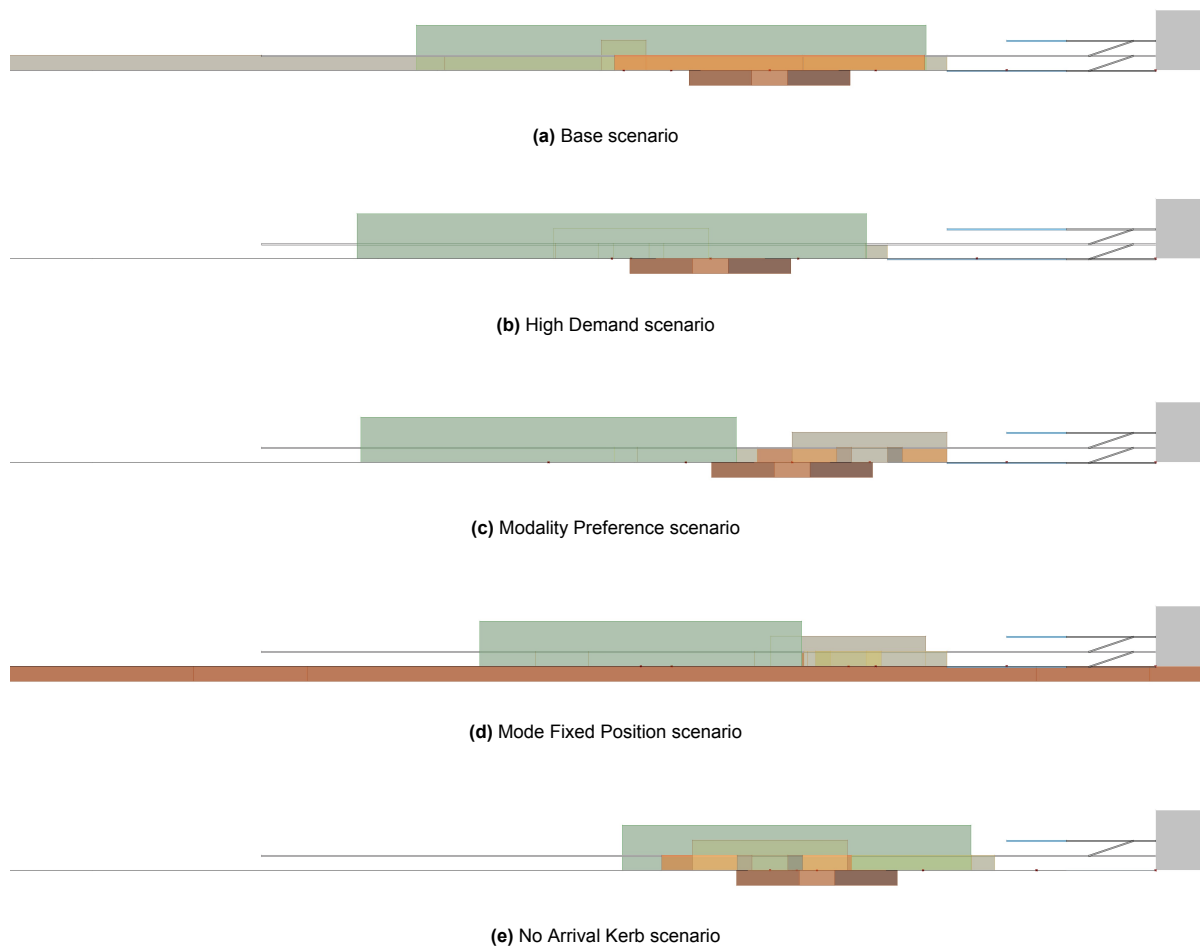


Figure A.1: Overview of the cross sections of all scenarios

B

Scientific Paper

Starting on next page.

Airport Landside Design: A Parametric Approach

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December 4, 2025

Abstract

This research investigated how parametric modelling can support early-stage airport landside planning by enabling the systematic generation and evaluation of adaptable terminal configurations. Traditional landside design relies on static forecasts and rules of thumb, which provide baseline estimates but limit exploration of alternative layouts and integration of public transport. To address these limitations, a parametric model framework was developed, translating demand, spatial, and performance parameters into a structured, data-driven approach. The model uses Excel inputs for passenger demand, modal splits, and basic geometry, generating landside layouts in Grasshopper through optimisation and scenario evaluation. Passenger experience is represented by walking distance, providing a quantifiable performance metric, while multiple scenarios illustrate how layouts respond to changes in demand and design constraints. Results demonstrate that the parametric model enables rapid iteration, visualisation, and comparison of alternative designs, improving decision-making transparency and adaptability. While simplifications such as 2D representation, partial passenger experience metrics, and solver stochasticity limit full applicability, the framework provides a foundation for more data-driven, flexible, and collaborative landside planning. Recommendations for future research include 3D modelling, enhanced passenger experience metrics, and alternative optimisation methods.

Keywords: *Airport Landside, Parametric Design, Rhino, Grasshopper, Galapagos*

1 Introduction

1.1 Context

As global air travel grows, airport infrastructure faces increasing pressure to handle higher passenger volumes, diverse traveller needs, and sustainability demands. While airport design often highlights airside capacity and terminal interiors, the landside (access roads, kerbsides, parking, and public transport connections) is equally important for performance and accessibility. Efficient landside layouts are essential to handle increasing capacity while maintaining a high Level of Service (LoS).

Traditional design approaches lack adaptability and often fail to integrate landside planning with public transport, resulting in inefficient space use, congestion, reduced passenger convenience, and restricted airport growth. Given rising demand for integrated and multimodal transport, landside design requires approaches that consider influencing factors such as demand uncertainty, transfer passenger share, and modal availability. This research addresses these gaps by integrating KPIs such as walking distance into a parametric model that enables faster testing of adaptable landside layouts.

1.2 Research Gap

Most airport landside planning relies on static forecasts and “rules of thumb”, which lack flexibility and precision and can lead to inefficiencies. This issue is becoming

more important as airports shift toward sustainable transport modes and face space constraints that limit continued reliance on car access. Despite the increasing importance of public transport accessibility, its physical integration is still not embedded well in the design process.

Parametric and generative design methods allow faster testing of alternatives and better adaptation to future changes, but have not yet been implemented for the landside context. Existing methods from other fields show potential, highlighting the absence of a data-driven tool for landside planning that incorporates physical public transport integration.

1.3 Research Objective

The objective of this research is to develop a structured approach for airport landside design based on key performance indicators (KPIs) and benchmarking. The goal is to create a parametric model that enables adaptable, data-driven configurations based on demand forecasting, while ensuring that public transport is physically integrated into the landside infrastructure.

1.4 Research Scope

This research focuses on airport landside infrastructure in front of the passenger terminal, including airport roadways, kerbsides, parking, car rental facilities, and public transport stations (rail, MRT, bus). Internal terminal components such as check-in, security,

and baggage handling, as well as stand-alone public transport stations, cargo areas, long-term parking, and other remote facilities, fall outside the scope. Both greenfield and brownfield settings are considered, but to limit complexity, brownfield conditions are simplified to “semi-greenfield” situations that keep only fixed boundaries and essential infrastructure. The model uses a “blank-canvas” approach, taking only the terminal location and landside boundaries as inputs. The aim is to support complex decision-making by generating and evaluating alternative landside configurations based on parameters and KPIs.

1.5 Research Questions

The central question guiding this research is:

In what way can a data-driven parametric model make the design and evaluation of airport landside configurations more flexible and adaptive?

This is explored through the following sub-questions:

1. How are airport landsides currently designed, and which design rules can serve as input for a parametric model?
2. What are the key design parameters for modelling airport landside performance, with particular attention to passenger experience?
3. What is needed for a parametric model to generate and evaluate landside configurations based on scenario inputs?

2 Research Methodology

2.1 Research Methods

The research approach combines literature review, expert consulting, data exploration, and parametric modelling. The literature review establishes the theoretical foundation, focusing on current landside design practices, public transport integration, design parameters, KPIs, and modelling strategies. Expert consulting with airport planners and architects at NACO complements the literature review by providing practical insights on layout trade-offs, uncertainty, and stakeholder interests, ensuring alignment between the model and real-world planning practice.

Data exploration is used to identify relevant and measurable parameters and to prepare available datasets for model use. The core of the research is the development of a parametric model that generates multiple landside configurations based on scenario inputs. The model is built around design parameters and layout principles identified earlier, and its performance evaluation is based on walking distance as the representation of passenger experience. The model is implemented in Excel, Python, Grasshopper, and Rhino, consistent with existing NACO workflows and ensuring transparency and reproducibility.

2.2 Tool Framework

The framework consists of different phases (1). It begins with the forecast, which defines MAP, air traffic movements, and the resulting passenger and employee demand. These inputs determine the modal split and lead to demand profiling, identifying peak-hour volumes. Together with reference values from the database, these inputs generate the landside capacity requirements such as kerb length, parking capacity, road capacity, and the number of public transport platforms.

These requirements feed into the parametric model, which performs a single-objective optimisation based on walking distance and generates landside configurations for the given scenario. Alternatively, users may manually position landside elements, allowing the tool to evaluate the layout with the same KPIs. Each output consists of a layout, objective value, and associated indicators.

Lastly, a performance evaluation compares configurations. Design adjustments can be made, supported by a feedback loop that allows modifying the capacity requirements or returning to the initial forecast.

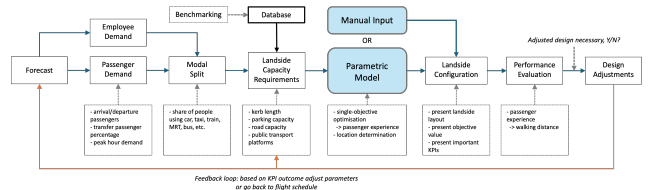


Figure 1: Framework of the Parametric Decision Support Tool for airport landside design

2.3 Output

The research produces a functional parametric model for airport landside planning. The model generates alternative landside configurations and calculates key performance indicators using real-world data. It consists of an Excel file for input parameters, a Rhino/Grasshopper environment for layout generation, and a visual and numerical output of configurations and KPIs.

Scientifically, the research applies generative and parametric design principles to airport landside planning and offers a replicable methodology integrating demand, spatial, and public transport parameters. This enables structured early-stage design, faster scenario testing, and more transparent, data-driven decision-making.

3 Literature Review

3.1 Search strategy

The literature search focused on airport landside design, public transport integration, decision support tools, parametric design, and passenger experience. Papers had to be published in academic journals within

the last twenty years and be relevant to these concepts. Forward and backward snowballing was used to identify additional relevant studies. Selection criteria included relevance of abstracts, discussion, and conclusions, as well as alignment with the research scope.

3.2 Literature overview

3.2.1 Airport landside

Airport landside design traditionally relies on annual passenger forecasts and peak-hour demand estimates. These forecasts are translated into design requirements using rules-of-thumb (Dimitriou et al., 2025). Such methods convert design hour flows into area requirements but have limitations in accuracy and adaptability (Jones & Pitfield, 2007). Conventional planning often results in inefficiencies, suboptimal resource allocation, and fragmented design of landside systems. Currently, there is no integrated approach that combines all landside systems while considering public transport integration. More dynamic, data-driven methods are needed to improve early-stage planning and accommodate variable passenger flows.

3.2.2 Public transport integration

Integrating public transport is critical for improving airport accessibility and reducing congestion (Mrníková et al., 2017). Public transport usage is most effective when designed as a seamless, integrated system. Integration must consider both the multimodal network of all routes and the operational and physical components of individual modes (Fang & Zimmerman, 2015). Proper integration increases passenger satisfaction and competitiveness of public transport versus private vehicles. Despite its importance, public transport planning is often poorly embedded in airport landside design, highlighting the need for integrated decision support methods.

3.2.3 Decision support tools

Airport planners currently lack tools that provide an integrated overview of the landside and allow evaluation of trade-offs between key performance indicators (Zografos et al., 2010). Existing tools are limited to specific tasks, such as sizing terminal zones or generating layouts based on predefined geometrical criteria (Sitek & Masły, 2018), and do not cover the entire landside system. Parametric and simulation-based tools can support decision-making by quickly generating alternative configurations, enabling scenario testing, and supporting more adaptable designs.

3.2.4 Parametric design

Parametric and generative design methods are increasingly used in architecture, urban planning, and building layout optimisation. They allow designers to link parameters to geometric outcomes, iteratively explore

alternatives, and evaluate performance criteria ((Weber et al., 2022), (Laignel et al., 2021), (F. Jiang et al., 2024), (Bielik et al., 2022)). Tools such as Grasshopper for Rhino enable iterative testing without traditional coding. Optimisation plug-ins like Galapagos allow automated search for best-performing design options. These methods have been applied to floor plan generation, apartment layouts, and urban design ((Turrin et al., 2011), (Janssen & Stouffs, 2015), (Caldas, 2008)), showing potential for rapid scenario testing and data-driven decision-making. Applying these methods to airport landside design could support the integration of public transport and optimisation of passenger flows.

3.2.5 Passenger experience

Passenger experience at airports depends on operational efficiency and comfort ((International Air Transport Association, 2022), (Boersma, 2025), (H. Jiang & Zhang, 2016)). While architectural design is important, passenger experience is determined by how efficiently passengers navigate the landside and interact with public transport. Four quantifiable aspects are particularly relevant:

1. **Minimise Walking Distances:** Routes should be as simple as possible; longer distances can be mitigated with mechanical assistance.
2. **Minimise Level Changes:** Level changes within the same journey should be minimised; separation of departing and arriving flows may require additional levels.
3. **Minimise Conflict Points:** Reduce pedestrian-vehicle interactions, especially at kerbs and shared spaces.
4. **Separation of Passenger Flows:** Separate passenger flows (e.g., arriving/departing, domestic/international) to reduce congestion.

Research shows walking distances and level changes strongly influence passenger behaviour, route choice, and satisfaction ((Bandara & Wirasinghe, 1992), (Daamen et al., 2005), (Braaksma, 1977), (De Neufville et al., 2002), (Popovic et al., 2010)). Gate scheduling, terminal configuration, and spatial layout directly affect walking distances, highlighting the need for integrated design and careful planning of flows and access points.

3.2.6 Discussion

Most landside planning relies on static forecasts and rules-of-thumb ((Dimitriou et al., 2025), (Jones & Pitfield, 2007)). Public transport and passenger experience considerations are often insufficiently embedded ((Fang & Zimmerman, 2015), (Mrníková et al., 2017)). Parametric design methods allow rapid testing of alternatives and support more adaptable, informed design decisions ((Zografos et al., 2010), (Sitek & Masły, 2018)).

The key knowledge gap is the absence of a flexible, data-driven parametric tool for landside planning that incorporates passenger experience and enables rapid scenario testing. Such a tool could automate repetitive tasks, support early-stage design decisions, and improve adaptability to changing conditions.

4 System Analysis of Airport Landside

4.1 Overview of Airport Landside Systems

Airports consist of airside and landside domains. The landside covers the infrastructure connecting the terminal to the surrounding transport network, such as terminal roads, kerbside areas, parking lots, rental car facilities, and public transport stations. This research focuses on the terminal area immediately in front of the terminal building, where passenger access and transfers occur, excluding cargo areas, long-term parking, and internal terminal circulation systems.

4.2 Demand

Landside demand originates from three main groups:

- **Passengers:** Only originating and destination (O/D) passengers are considered, adjusted for transfer passengers and reporting factors to reflect peak hour demand.
- **Employees:** Both airport and commercial employees generate landside demand, particularly during peak operational periods, derived from staffing levels and schedules.
- **Visitors, Delivery, and Maintenance (VDM):** These trips are estimated as a proportion of total employee demand.

Demand is distributed across transport modes (private cars, taxis, buses, public transport, and rental cars) and converted into vehicle flows and Passenger Car Equivalents (PCE) to size roads, kerbside, and parking facilities.

4.3 Physical Components

The main landside infrastructure components are sized based on peak hour demand:

- **Terminal Area Roadways:** Access roads, re-circulation lanes, and internal roads are designed to handle vehicle flows efficiently, ensuring smooth circulation.
- **Kerbside:** Vehicle stopping areas are calculated using peak arrivals, dwell times, and layout configurations, either combined or segregated by mode.

- **Parking:** Passenger and rental car parking is sized according to annual throughput and converted to area using standard bay dimensions and layout efficiency.
- **Public Transport Facilities:** Rail, MRT, and bus stations are planned for expected passenger loads, platform or bay numbers, and dwell times during peak hours.

4.4 System Constraints and Interactions

Landside planning is constrained by terminal layout, existing runways, surrounding roads, and nearby infrastructure. Underground stations, terminal entrances, and circulation patterns influence feasible roadway and kerbside configurations. Interaction between transport modes and terminal access points is critical to maintain efficient passenger flows.

4.5 Passenger Experience

Passenger experience is measured mainly through walking distance from transport facilities to terminal entrances. Direct paths minimise inconvenience, while centralized pedestrian routes reflect realistic behaviour. Kerbside walking distances are calculated separately.

5 Model Specification

5.1 Data Requirements and Data Analysis Tools

Data availability is critical for developing a parametric model. The model requires real-world reference data to define input parameters and evaluate design scenarios.

5.1.1 Data Requirements

To support both the input and output of the parametric model, the following data is required:

- **Passenger Demand:** Number of origin/destination passengers, transfer passenger share, and peak-hour demand profiles based on flight schedules.
- **Employee VDM Demand:** Demand generated by airport employees and visitors, delivery, and maintenance (VDM).
- **Modal Split:** Distribution of transport modes (car, taxi, public transport, etc.) to estimate vehicle flows, public transport usage, and kerbside demand.
- **Landside Infrastructure Dimensions:** Benchmark data from existing airports, including kerb length, parking capacity, road capacity, number of public transport platforms, and walking distances to terminal entrances.

Data mainly comes from internal NACO projects and benchmark Excel files.

5.1.2 Tools and Platforms

The primary tools used are:

- **Excel:** to manually calculate inputs for Grasshopper
- **Python:** to process Excel data for Grasshopper
- **Grasshopper:** to generate and optimise layout configurations
- **Rhino:** to visualise generated layouts
- **Python:** to process solver outcomes to obtain KPIs

These tools were selected for compatibility with NACO workflows and familiarity with the software.

5.2 Model Excel Input and Design Input

The tool consists of two parts: an Excel file and a Grasshopper model. Figure 2 shows the connection between them. The light purple area indicates the parametric model. Users can change input in Excel (planning parameters) or Grasshopper (design parameters via sliders and drop-down menus).

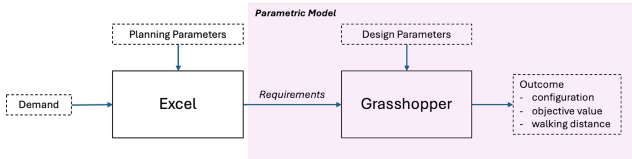


Figure 2: Connection Excel and Grasshopper showing the inputs, outputs and which part comprises the parametric model

The Grasshopper model fulfils three main functions, that can be seen as three steps that are performed one after the other. These three steps are shown in Figure 3.

1. Translation and visualisation of input data into geometries
2. Optimisation of spatial layout using Galapagos solver
3. Evaluation of resulting layout with KPIs such as walking distances

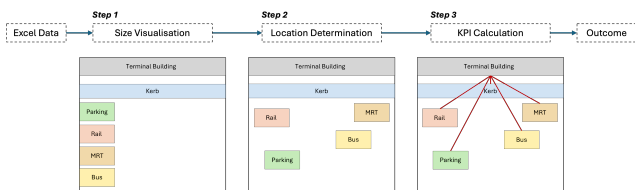


Figure 3: The three steps of the Grasshopper model

Table 1 shows all the adjustable design parameters that serve as input for the Grasshopper model. For each design parameter, the table indicates the type of parameter (slider or drop-down menu) and its range or available options. For drop-down menus, common options are included. For number sliders, ranges are based on existing airports and allow for further experimentation. This table provides transparency on how the model can be configured and which parameters influence the layout optimisation.

Table 5.1: Adjustable design parameters Grasshopper, indicating the type and range/options for the parameter ¹

Grasshopper Module	Design Parameter	Type	Range/Options
Excel	Input	Panel	File Path
Landside	Length	Slider	50 - 2000
	Width	Slider	50 - 2000
Terminal	Length	Slider	50 - 2000
	Width	Slider	50 - 500
	Offset	Slider	30 - 100
	Entrances	Slider	1 - 20
Walking Routes	Layout Option	Drop-down	0. Centralised 1. Decentralised
Spine	Add Option	Drop-down	0. Spine 1. No Spine
	Width	Slider	5 - 100
Kerb	Layout Option	Drop-down	0. Segregated Kerb 1. Combined Kerb 2. No Arrival Kerb
Parking	Forecourt Size	Slider	5 - 50
	Rental Option	Drop-down	0. Rental in STP 1. Rental not in STP
	Percentage STP	Slider	0.00 - 1.00
	Number of Floors	Slider	1 - 10
Rail	Level Option	Drop-down	0. Above Ground 1. Under Ground
	Station Option	Drop-down	0. End Station 1. Intermediate Station
	Built Option	Drop-down	0. Can Build on Top 1. Cannot Build on Top
MRT	Level Option	Drop-down	0. Above Ground 1. Under Ground
	Station Option	Drop-down	0. End Station 1. Intermediate Station
	Built Option	Drop-down	0. Can Build on Top 1. Cannot Build on Top
Bus	NO INPUT	-	-
Preferences	Weight Parking	Slider	0.1 - 10.0
	Weight Rail	Slider	0.1 - 10.0
	Weight MRT	Slider	0.1 - 10.0
	Weight Bus	Slider	0.1 - 10.0

¹. All the provided ranges are continuous ranges, the options are discrete choices, the statistical significance is also shown

5.3 Model Structure and Logic

To built something in Grasshopper, "components" need to be placed on the Grasshopper canvas. These components need to be connected to each other through "wires", multiple connected components can form a "cluster" which can perform a certain task. Figure 4 shows the cluster overview with directionality. Green clusters are inputs, orange clusters feed the solver, which produces visual and numerical outputs.

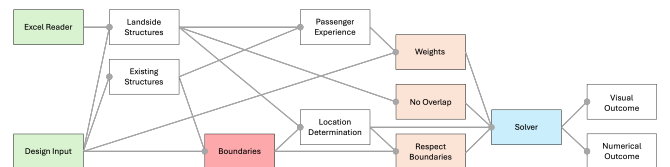


Figure 4: Overview of the Grasshopper clusters where the lines with dots show the connections and directionality

The main clusters include:

- *Excel Reader:* reads and translates Excel input
- *Design Input:* user sliders and drop-downs
- *Existing Structures:* terminal and boundaries

- *Landside Structures*: geometries of landside elements
- *Boundaries*: constraints for placement
- *Location Determination*: sets X, Y, and rotation of structures
- *Passenger Experience*: calculates walking distances
- *Respect Boundaries*: penalty if boundaries are crossed
- *No Overlap*: penalty if structures overlap
- *Weights*: prioritises certain structures or modes
- *Solver*: Galapagos component minimises objective function
- *Visual Outcome*: visualises optimal layout
- *Numerical Outcome*: presents KPIs and alternative options

Table 2 shows the input parameters that Galapagos can change during optimisation. Each landside structure has sliders for X-coordinate, Y-coordinate, and rotation. The table summarises the range of values for each slider. This table provides a clear overview of how the solver can explore the solution space and which parameters it controls.

Table 5.2: Input parameters for Galapagos ²

Landside Structure	Design Parameter	Type	Range/Options
Parking	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1 (0°, 180°)
	Ratio Length-to-Width	Slider	1.0 - 2.5
Rail	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1, 2, 3 (0°, 90°, 180°, 270°)
	Ratio Length-to-Width	Slider	1.0 - 2.5
MRT	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1, 2, 3 (0°, 90°, 180°, 270°)
	Ratio Length-to-Width	Slider	1.0 - 2.5
Bus	X-Coordinate	Slider	0.00 - 1.00
	Y-Coordinate	Slider	0.00 - 1.00
	Rotation	Slider	0, 1 (0°, 180°)
	Ratio Length-to-Width	Slider	1.0 - 2.5

²: All the provided ranges are continuous ranges, the options are discrete choices indicating the rotation, the statistical significance is also shown

5.4 Model Objective and Scope

The model performs a single-objective optimisation, equation 1 shows the objective function which minimises walking distances while penalising overlap and boundary violations:

$$\begin{aligned}
 MIN. \quad & \text{walking distance} \times \text{peak hour weight} \times \\
 & \text{designer preference weight} \\
 & + \text{overlap} \times \text{overlap penalty} \\
 & + \text{boundary} \times \text{boundary penalty} \quad (1)
 \end{aligned}$$

5.5 Model Optimisation

Galapagos (Grasshopper) explores parameter combinations to find near-optimal solutions. It has two solvers: evolutionary and annealing.

Key definitions:

- **Inputs (genes)**: sliders that Galapagos can adjust

- **Fitness Function**: number to minimise (walking distance)
- **Solver Type**: evolutionary or annealing

The evolutionary solver in Galapagos searches for solutions by generating a population, evaluating their fitness. It then iteratively improves the solutions through methods such as mutation and recombination. This helps the solver to explore a wide range of configurations but sometimes causes the solver to converge prematurely on sub-optimal solutions (Tait, 2025). The simulated annealing solver uses a different approach. It starts with wide, exploratory moves and occasionally accepts worse solutions to escape local optima. As the “temperature” decreases, the search becomes more focused and controlled (Rutten, 2011).

6 Model Outcomes

6.1 Scenario Setup

To evaluate the robustness and flexibility of the model, a number of scenarios are created that represent different demand levels and design priorities. The same model structure and constraints are used for each scenario, but different input parameters and weighting factors are applied for the various landside components.

The following scenarios were tested:

- *Base Scenario*: Neutral designer preferences and normal peak-hour demand levels to create a base scenario for the other scenarios.
- *High Demand Scenario*: Increased demand across all modes (+100%) to evaluate how this influences the spatial configuration.
- *Modality Preference Scenario*: Add weight to one specific mode to evaluate how designer preference can influence the location of that weighted mode.
- *Mode Fixed Position Scenario*: Fix the position of one mode to see how the other modes are optimised around it.
- *No Arrival Kerb Scenario*: Remove the arrival kerb to see the impact on the other modes, especially the parking.

Each scenario is run by the annealing solver from Galapagos to find the landside configuration that minimises the weighted walking distance while respecting the boundary and non-overlap constraints.

6.2 Optimisation Process

The optimisation was done using the built-in solvers from Galapagos within Grasshopper, in combination with Rhino. Both the Evolutionary Solver and the Annealing Solver were tested to determine which of the two performs best for the parametric landside layout problem.

Since the optimisation problem includes both discrete and continuous variables, non-linear relationships, and hard spatial constraints like avoiding overlaps and respecting boundaries, the Evolutionary Solver initially seemed the best choice. However, in practice, it often converges too quickly to local optima.

The Annealing Solver, in contrast, explores the solution space more broadly at the start and accepts temporarily worse solutions to escape local optima. This gradual improvement allows the solver to reach more consistent and higher-quality solutions across iterations, making it more appropriate for this research.

6.3 Model Results

This section presents the optimised configurations for each scenario. Each figure shows a visual outcome (spatial configuration with walking paths) and a numerical outcome (objective value and average walking distances).

6.3.1 Base Scenario

The Base scenario represents normal demand and equal weighting across all modes. It is intended to serve as a benchmark, showing the default behaviour of the model without any design preferences or extreme demand variations.

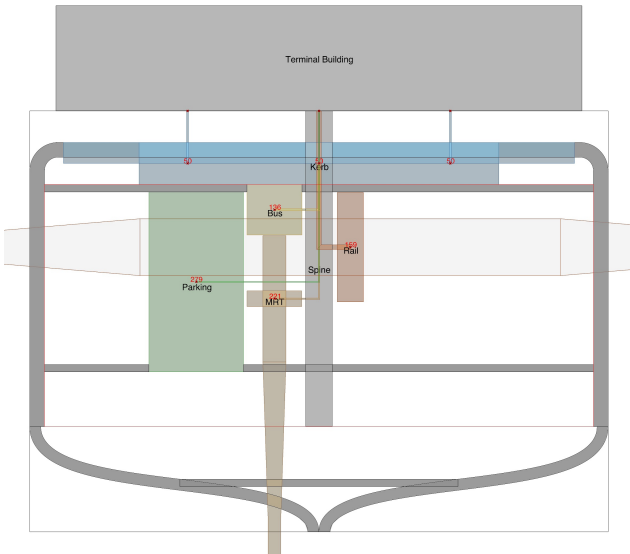


Figure 5: Model outcomes of the Base scenario

Explanation: In the Base scenario, modes with higher passenger volumes are placed closer to the terminal to minimise average walking distances. The distribution of modes appears balanced, reflecting the

equal weighting of all modes in the objective function. This scenario establishes a reference point for comparing other scenarios.

6.3.2 High Demand Scenario

The High Demand scenario doubles the yearly demand to evaluate how increased passenger volumes influence the landside configuration.

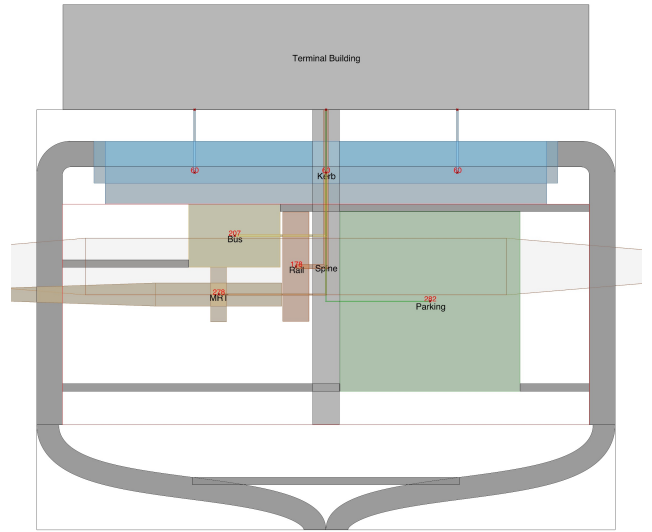


Figure 6: Model outcomes of the High Demand scenario

Explanation: With higher demand, the model places more emphasis on modes that can accommodate larger flows close to the terminal, while smaller modes are slightly pushed outward. This results in a larger overall footprint, and walking distances increase slightly due to the expanded space required to accommodate all passengers.

6.3.3 Modality Preference Scenario

This scenario simulates a designer-driven context where one mode, in this case the MRT, is given higher weighting in the objective function.

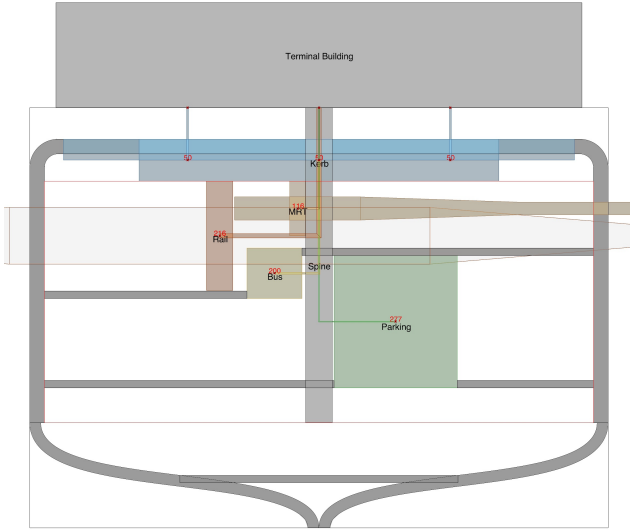


Figure 7: Model outcomes of the Modality Preference scenario (MRT)

Explanation: By prioritising the MRT, the model positions it closer to the terminal, reducing walking distances for the majority of passengers using this mode. Other modes adjust their positions accordingly, showing that designer preferences can effectively influence the spatial layout without violating constraints.

6.3.4 Mode Fixed Position Scenario

In this scenario, the position of the Rail mode is fixed, and the optimisation adjusts the remaining modes around it.

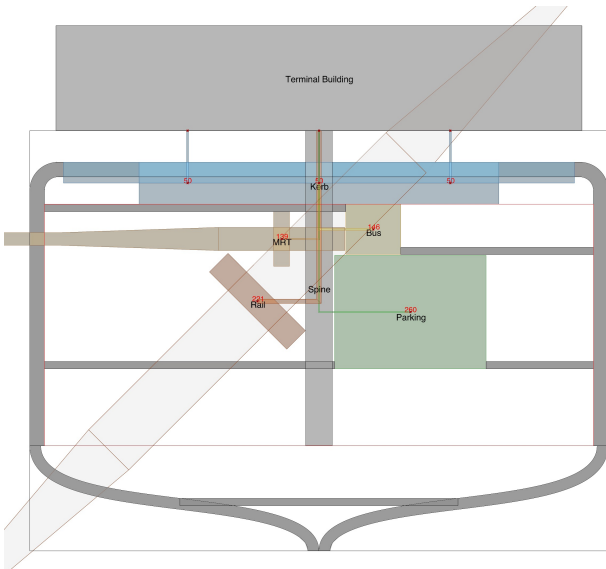


Figure 8: Model outcomes of the Mode Fixed Position scenario (Rail)

Explanation: Fixing the Rail mode limits the solution space and forces other modes to adapt. The model finds optimal positions for the remaining modes that maintain low walking distances while respecting the

fixed position. This scenario demonstrates how constraints on specific modes influence the overall configuration.

6.3.5 No Arrival Kerb Scenario

The arrival kerb is removed to examine its influence on mode accessibility and spatial organisation.

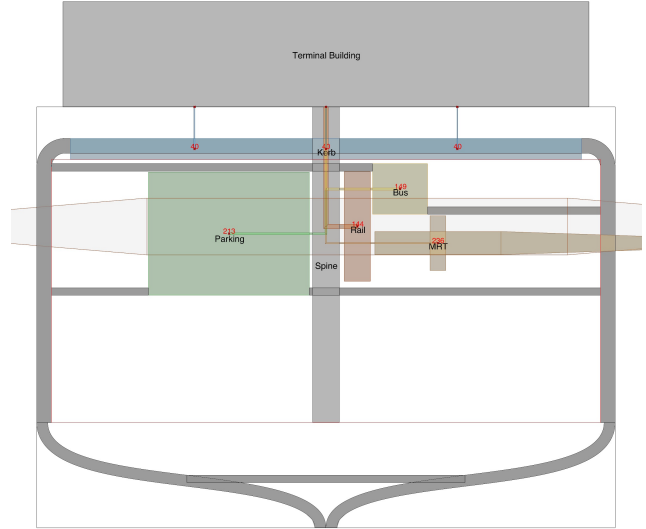


Figure 9: Model outcomes of the No Arrival Kerb scenario

Explanation: Removing the arrival kerb allows other modes, particularly parking and drop-off, to move closer to the terminal. Walking distances for passengers decrease slightly for some modes, while the overall configuration becomes more compact. This highlights the role of physical infrastructure constraints in shaping landside layouts.

6.4 Discussion of Model Outcomes

The scenarios show that the parametric model produces logical and interpretable landside configurations that react as expected to different inputs. Modes with higher demand are consistently placed closer to the terminal.

Key observations:

- **High Demand:** Larger landside structures increase walking distances.
- **Modality Preference:** Designer weighting effectively places the preferred mode closer to the terminal.
- **Mode Fixed Position:** Fixed Rail position leads to small improvements in total walking distance due to new rotational possibilities.
- **No Arrival Kerb:** Removal of kerb allows other modes to move closer to the terminal, improving accessibility.

Overall, the model responds predictably to both quantitative and qualitative inputs, providing interpretable results and supporting early-stage master planning decisions.

7 Conclusion & Discussion

7.1 Conclusion

This research developed a parametric model framework, supported by a prototype, to generate and evaluate airport landside configurations for passenger terminals. The model translates demand, spatial, and performance parameters into a structured framework, enabling systematic exploration of design alternatives.

Airport landsides are designed to accommodate multiple transport modes, using static forecasts and rules of thumb from IATA, ICAO, and ACRP guidelines. While these methods provide quick baseline estimates, they are limited in exploring alternative layouts or integrating public transport. The parametric model builds on peak-hour demand and rules of thumb but allows iterative testing of layout interactions, providing insight into spatial performance rather than improving the forecast itself.

The system analysis identified demand parameters, spatial parameters, and performance indicators as essential for modelling landside performance. Passenger experience was represented by walking distance, providing a quantifiable metric, although other aspects such as level changes or conflict points were not included. Drawing on parametric methods from architecture and urban planning, the model enables rapid evaluation and comparison of alternatives.

The model uses Excel inputs for demand and geometry, generating landside layouts in Grasshopper through translation, optimisation using the Galapagos annealing solver, and evaluation. Different scenarios demonstrate the model's ability to respond to quantitative and qualitative changes, providing interpretable insights into spatial trade-offs and supporting early-stage decision-making. Limitations include solver stochasticity and lack of transparency, suggesting the need for sensitivity analysis. Overall, the parametric model supports early design by generating multiple layouts quickly and providing systematic comparisons of spatial trade-offs and passenger accessibility. While usable as a support tool, simplifications such as 2D representation, partial capture of passenger experience, and solver opacity limit its broader applicability. Nonetheless, the model has potential to enhance adaptability, transparency, and data-driven decision-making.

7.2 Discussion

The model demonstrates the potential of automation to support early-stage landside planning, integrating demand, geometry, and performance efficiently. The representation of passenger experience through walking distance provides a clear objective for optimisation, but does not capture 3D effects, level changes, or conflict

points. The 2D simplification cannot fully represent complex terminal geometries, and the Galapagos solver operates as a "black box," producing slightly different results across runs. The conceptual abstraction, tested on linear layouts, limits applicability to unconventional terminal configurations. Despite these constraints, the model provides a foundation for scenario testing, spatial evaluation, and iterative design exploration.

7.3 Recommendations

Future research could explore alternative optimisation approaches or solvers, including solutions outside Grasshopper, to improve transparency and flexibility. Expanding passenger experience metrics beyond walking distance and including additional landside components or 3D representation would enhance realism. Simplifying the model by focusing on manual layout adjustment while retaining parametric evaluation could maintain flexibility and improve designer control.

For practical application, NACO could consider whether a generalised model, adaptable to multiple airport layouts, or a specialised model, focused on a common typology, better fits project goals. Integration with existing Excel datasets and the creation of interactive dashboards could improve usability for planners and stakeholders. The parametric approach could also be extended to other domains such as urban mobility, infrastructure planning, or master planning, supporting early-stage decision-making through automated generation, KPI evaluation, and visual feedback.

Overall, this research demonstrates that parametric modelling has the potential to make landside planning more adaptable, transparent, and data-driven, providing a structured tool for early-stage design exploration while highlighting areas for further refinement.

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